ESSENTIALS OF MEDICAL ELECTRICITY

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BY

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THIRD EDITION, REVISED AND REWRITTEN WITH ADDITION OF NEW MATTER

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WITH ELEVEN PLATES AND SEVENTY-TWO ILLUSTRATIONS

ST. LOUIS

C. V. MOSBY COMPANY

1916

PREFACE TO THE THIRD EDITION

SINCE the appearance of the last edition of the present work considerable advances have been made in the subject of medical electricity. New and important methods have been introduced, while the mode of action of electricity in the treatment of disease is now more clearly understood.

The author of the present edition has therefore found it necessary to rewrite and rearrange the work so as to include the new methods and, at the same time, present the subject in the light of the newer and clearer knowledge of the way in which electricity acts in the cure or relief of disease.

The different methods of electrical treatment have been considered in separate chapters. The title of the book compels the insertion of a chapter dealing with the elementary physical principles of electricity, for knowledge of the latter is essential for the successful practice of electro-therapy. The chapter dealing with this part of the subject has been placed at the end of the book, so that those who have not forgotten the elements of the physics of electricity can commence, as soon as possible, the chapters dealing with the application of electricity for medical purposes.

E. P. C.

15 UPPER WIMPOLE STREET, W.
1916.

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Essentials of Medical Electricity

INTRODUCTION

THE subject of the present volume is the use of electricity for the treatment of disease. Although the precise nature of electricity is unknown, its mode of action on the body is now more clearly understood, and it is being gradually recognised that its physiological and therapeutic effects are the consequence either of chemical or physical changes that it brings about in the tissues. The nature of these chemical and physical changes will be set forth in Chapter I. In many cases it is quite clear how electricity, by bringing about these changes, can cure disease or relieve its symptoms; in others it is less evident; but so long as we look upon the unknown agent electricity as an agent which produces known chemical and physical effects, we are enabled to see more clearly which diseases and morbid conditions are likely to benefit and render less empirical their electrical treatment.

For the practice of medical electricity a sound knowledge of physics is necessary, for, without it, the principles of the subject and even the meaning of the terms in everyday use will not be understood, and it will be impossible to discover and put right simple failures of the apparatus when they occur. Those whose knowledge of physics has grown grey will find a brief outline of the physical principles of electricity and explanations of the terms in common use in Chapter XV.

With the exception of its use in testing the reactions of muscle and nerve, electricity deals almost entirely with treatment. Of the maladies for which it is used, there are some for which it procures cure or relief where other methods have failed, or where other methods are slower and less efficacious. There are other maladies, incurable by any known method, for which electrical treatment is still sometimes requested, cases which drift down, like derelicts, to the electrical departments of hospitals on the chance that some benefit may be derived there. There is a third group of maladies comprising the diseases of which the *symptoms* can be relieved by electrical treatment. For these, electricity is *part* of the treatment of the disease, and if it is to yield the best results the general treatment should not be neglected. There is, now, no region of the body to which electrical treatment is not applied, and it is essential that the practitioner of electro-therapeutics should have a general experience of medicine as well as a special knowledge of the subject dealt with in the present book, while the prescriber should be acquainted with the field of medical electricity, so that the treatment may be administered only to suitable cases.

CHAPTER I

THE MODE OF ACTION OF ELECTRICITY ON THE BODY

It has been mentioned in the Introduction that the physiological and therapeutic action of electricity is due to chemical or physical changes which it produces in the tissues. The way in which these changes are brought about will be best understood by the study of the passage of an electric current through water containing a salt in solution. If two wires leading from the poles of a battery are immersed in water without touching, and a milliampere-meter is placed in circuit, no current will be indicated if the water is perfectly pure and contains no salts in solution. The needle of the milliampere-meter will remain at zero. If now a salt such as sodium chloride is dissolved in the water, the current is able to flow and the needle of the milliampere-meter moves across the scale. The addition of any other salt will produce the same effect, provided it is soluble in water. So also will a soluble base (such as sodium hydrate) or a soluble acid. These bodies, when dissolved, form solutions that enable the current to flow, and are known as "electrolytes." In the dry, undissolved condition they do not conduct the electrical current any more than the pure water, but in solution they undergo change, so that the current is able to pass. If, instead of a salt or base or acid, some albumen or other soluble protein, free from salts, is dissolved in pure water, no current will flow. If starch or dextrine or dextrose is dissolved, still no current will flow. Proteins and carbohydrates, and other chemicals such as

alcohol and phenol do not, when they pass into solution, enable the electric current to pass: they are not electrolytes. The first important point to be observed with regard to the passage of the electric current through the body is this—the tissues conduct the electric current because they contain electrolytes—viz. salts in solution. The tissue protoplasm and its products are not themselves conductors of this current, but the latter can pass through them because they are permeated with fluid that contains salts in solution.

To return to the experiment on the passage of the current through the solution of salt. The passage of the current is not the only phenomenon observed. Chemical changes are at the same time taking place. One of these is evident. Bubbles of gas (hydrogen) are seen escaping in the region where the current is leaving the solution. Other chemical changes are taking place at the same time and will be mentioned in due course.

It is now necessary to consider more in detail the nature of these chemical changes and how they are brought about. When an electrolyte dissolves in water (thereby enabling the current to pass) it undergoes certain changes. It is generally believed that in the process of solution a certain proportion of the molecules divide or dissociate into two parts, each part taking an electrical change. These electrically charged parts are known as "ions." Thus when a molecule of sodium chloride dissolves in water it divides into two parts, one, the sodium ion, bearing a positive charge ($\overset{+}{Na}$), the other, the chlorine ion, bearing a negative charge ($\overset{-}{Cl}$). The ions have properties quite different from those of the unelectrified atoms. A solution of sodium chloride contains sodium ions, and chlorine ions, and in addition undivided molecules of sodium chlorides. The ions take no particular course, but move about in any direction, sometimes

reuniting with others, reforming the molecule, which again dissociates, and so on. When, however, an electric current flows through the solution, the ions move in definite directions. Those with the positive charge (the sodium ions) move in the same direction as the current, and those with the negative charge (the chlorine ions) move in the opposite direction. This orderly movement of the ions is due to the following causes. The conductor along

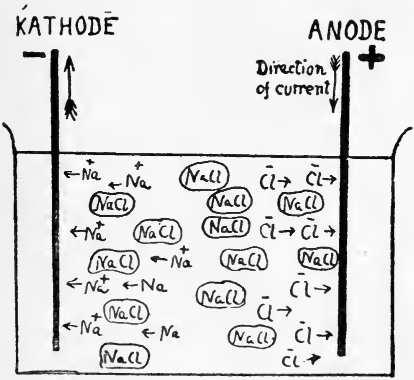


FIG. I.—Passage of current through a solution of sodium chloride. Sodium ions migrating to kathode, chlorine ions to anode. Undivided sodium chloride molecules move in no definite direction.

which the current *enters* the solution (known as the positive electrode, or *anode*) is connected to the positive pole of the battery, and therefore the ions with the positive charge are *repelled* from it. At the same time they are *attracted* to the conductor by which the current *leaves* the solution (the negative electrode, or *kathode*), because this conductor is connected to the negative pole at the battery. The ions with the negative charge make their way in a direction opposite to that taken by those with the positive charge, because they bear the opposite charge. The

ions with the positive charge, therefore, travel in the same direction as the current "down-stream," while those with the negative charge make their way in a direction opposite to that of the current "up-stream." Those events are shown diagrammatically in Fig. 1. Now when the ions reach the electrodes to which they are attracted, their electrical charges are neutralised and further chemical changes occur. These depend on the nature of the ion and on the material of which the electrodes are made. Assuming that the electrodes are made of a metal like platinum, which resists corrosive action, the positively charged sodium ion reaches the kathode and its electrical charge is neutralised, whereupon the sodium, now in the free unelectrified state, resumes the properties of free sodium and decomposes the water, forming sodium hydrate (caustic soda) and free hydrogen. The negatively charged chlorine ion reaches the anode and becomes free chlorine, some of which, in the nascent state, decomposes the water, forming hydrochloric acid and oxygen (Fig. 2). These are not the only changes that take place at the poles. It will be sufficient, at this stage of our inquiry, to say that bodies of an alkaline reaction form at the negative electrode (kathode). If red litmus is around this electrode it will turn blue. If the positive electrode (anode) is made of some metal that resists the action of acids, such as platinum, acids will be formed around this pole and can likewise be demonstrated by litmus.

The passage of the electric current through the solution, therefore, produces two main changes. In the first place, the ions between the electrodes of entry and exit of the current migrate in definite directions, those with the + charge migrating towards and accumulating at the negative electrode, those with the − charge migrating towards and accumulating at the positive electrode. There is therefore a redistribution of ions *between* the

electrodes along the path of the current. In the second place, new chemical bodies are formed *at* the electrodes.

When a current of electricity passes through any part of the body, similar events take place. The tissue fluids contain many other salts besides sodium chloride—viz. carbonates, chlorides, phosphates and sulphates of

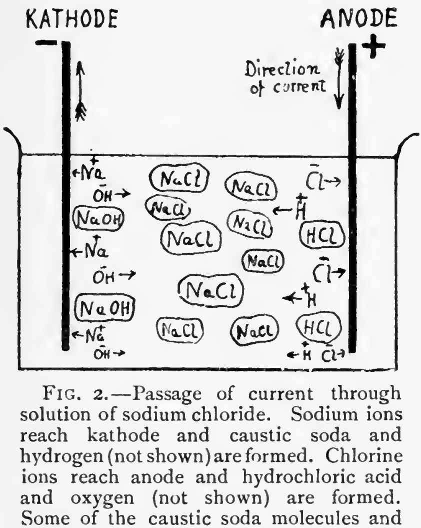


FIG. 2.—Passage of current through solution of sodium chloride. Sodium ions reach kathode and caustic soda and hydrogen (not shown) are formed. Chlorine ions reach anode and hydrochloric acid and oxygen (not shown) are formed. Some of the caustic soda molecules and hydrochloric acid molecules dissociate and form ions $\overset{+}{Na}$ and $\overset{-}{OH}$; and $\overset{+}{H}$ and $\overset{-}{Cl}$.

sodium, potassium, calcium, magnesium and iron, besides organic soluble salts, so that there are other ions as well as the sodium and chlorine ions. The two last-mentioned are, however, present in the largest number. The sodium hydrate which forms at the negative electrode has a caustic action on the tissue. So also has the hydrochloric acid which forms at the positive electrode. Either may be used for the destruction of tissue. This, the so-called electrolytic action of the current on the

tissue, is really the chemical action of the caustic products formed at the electrodes. Here we have one of the examples of the mode of action of electricity on the body by the production of chemical changes. The electrical current acts in this way when it is used for the destruction of nævi, warts, moles, etc., and the practical details of the method will be set forth in a later chapter. This method is sometimes spoken of as "surgical electrolysis" or "surgical ionisation."

There is, also, in the tissues, a migration of ions between the electrodes and a resulting redistribution. The conditions are more complicated in the case of the tissues than in the simple salt solution. There are various ions in the tissues and they are not in the same relative proportion or concentration in the various organs. Thus the tissues of the nervous system contain more potassium salts and phosphates, while the blood and lymph contain more sodium chloride and carbonate ; that is to say, in the former there are more $\overset{+}{\mathrm{K}}$ ions and $\mathrm{P\bar{O}_4}$ ions ; in the latter, more $\overset{+}{\mathrm{Na}}$ ions and $\mathrm{\bar{C}l}$ and $\mathrm{C\bar{O}_3}$ ions. When the current traverses these tissues there must be some rearrangement in the relative proportion of the various ions in them. When, in cases of disease, the application of the electric current produces a beneficial effect, the mode of its action may be found perhaps in the migration and redistribution of the ions in the diseased part, some upset in the balance having possibly taken place in the disease or possibly some new ions having been formed. It is, of course, very difficult in the present state of our knowledge to show the exact relation between ionic redistribution and therapeutic action. The following examples are suggestive as to the mode of action of the electric current by producing a redistribution of ions along the path of its flow.

The constant current has the power to quickly abolish

the feeling of fatigue from a heavily worked muscle. This was spoken of as the "refreshing" action of the current. What probably happens is as follows. Fatigue products (perhaps sarcolactic acid or its salts) accumulate in the muscle. The passage of the current through the muscle causes migration of these ions and many pass out of the muscle and into the blood vessels and lymphatics of the muscle and are then at once carried away by the circulating fluid.

The refreshing effect produced by passing the constant current through the brain (cerebral galvanisation) is possibly due to a similar action, the removal of fatigue products as a result of their migration accompanying the passage of the current.

The power of the current to produce migration of ions can be utilised for a third purpose. If a solution containing ions is placed in contact with any part of the body and the current made to traverse the solution on its way through the body, the ions will migrate as previously described, so that some will pass through the skin into the body, and others, bearing the opposite charge, will pass in the opposite direction out of the body. The electric current can therefore be used for the purpose of introducing electrolytes (or, more correctly, their ions) into the body. A large number of drugs used in medicine are electrolytes. The current can therefore be used for the purpose of introducing drugs into the tissues, and the method is known as the "ionic method."

We have, therefore, three examples of the way in which electricity produces therapeutic effects by means of the chemical changes which it can induce. These may be briefly re-stated :

1. The production of new chemical bodies at the electrodes of entry and exit of the current into and from the body. These bodies have a caustic action, and are used for the destruction of diseased

and unnecessary tissue. The process is known as "surgical ionisation."

2. The rearrangement of ions along the path of the current through the tissues.
3. The introduction of new ions from without. The process is called "medical ionisation," and the method is known as the "ionic" method.

The changes mentioned under 2 and 3 are on the border-line between chemical and physical; they may be called physico-chemical.

While the current is passing through the body it stimulates the excitable tissues, as indicated by the subjective sensations produced, such as pain, the feeling of burning and pins and needles. These sensations are in all probability the result of the movement of ions through the sensory nerves and end-organs. If the current flows constantly in the same direction and with strength unvaried, no muscular contraction is noticed. The steady movement of the ions stimulates sensory nerves, but not motor nerves or voluntary muscle. If, however, the movement of the ions is suddenly stopped by switching off the current, the muscles give a single twitch at the moment the current is interrupted. A single twitch is also noticed at the moment when the current is switched on again, and the movement of the ions again suddenly started. An abrupt start of ionic movement or cessation of movement is therefore necessary if voluntary muscle is to be stimulated to contract. The former happens to be a more effective stimulus than the latter, so that the twitch occurring at the moment when the current is switched on (the so-called "closure contraction") is larger than that occurring at the moment when the current is switched off (the "opening contraction"). Other tissues, besides muscle and nerve, are in all probability stimulated, and the beneficial action of electricity in the treatment of certain conditions (of which *paralysis*

may be mentioned as one) is not to be attributed to any mysterious or vital action of the electricity, but rather to the stimulation of the tissues produced by the ionic movement that is a necessary accompaniment of the passage of the electric current.

Just as a sudden movement in the same direction or sudden cessation of movement of ions will cause a voluntary muscle to contract, so will a sudden *reversal* of their movement. If the reversal is slow, the current slowly sinking to zero and then rising to its maximum with equal slowness, but in the opposite direction, there will be no contraction of muscle, but a sensation of smarting and pricking will be perceived, because the slow to-and-fro movement of the ions acts as a stimulus to sensory nerves, but not to voluntary muscle or motor nerves. If the reversal of the current becomes more frequent, the ionic oscillation will become sufficiently frequent to stimulate motor nerves and muscle, and contraction will occur. With a still greater frequency of current reversal and ionic oscillation all sensation will disappear, except that due to the contraction of the muscles. Finally, when the frequency of the current reversal becomes extremely high—a million or more reversals taking place each second (this is the so-called "high-frequency" current)—there will be no contraction of muscles and no stimulation of nerves, and there will be no chemical change of any kind.

This inability of the high-frequency current to produce the physiological phenomena that are brought about by the constant current or the current that oscillates with a lower frequency had, for many years, received no satisfactory or intelligible explanation. But if the phenomenon is considered in the light of the behaviour of the ions that accompanies the flow of the current, and the electrical stimulus regarded as a sudden ionic movement, it receives a satisfactory explanation. If the current

travels to and fro with a frequency of a million or more per second, the ions are unable to keep pace with it: they remain stationary, and there is no ionic movement. During the millionth part of a second for which the current is flowing in any one direction before it reverses, the ions have been unable to move, or, at any rate, to move sufficiently to bring about a stimulation of excitable tissue. Now that it is possible to pass an electric current through the body without stimulating the excitable tissue, and without producing chemical change, we are able to utilise electricity for the production of heat within the body. Since the high-frequency current does not stimulate the excitable tissues, it may be sent through the body in strength far greater than that permissible for constant or low-frequency current, and it will then develop heat on its path through the tissues as it overcomes their resistance. The constant current or low-frequency current are unable to act in a similar way, because they would produce violent muscular contraction and unbearable pain long before they reached a strength sufficient to develop heat. The heat that is generated by the high-frequency current is developed on the path along which it flows, so that the deep-lying tissues are heated as well as the superficial. The raising of the temperature of the deep as well as the superficial tissues is known as "diathermy." It forms an important branch of medical electricity, and is described in Chapter XII.

High-frequency currents were used in medicine for many years without a clear knowledge of the way in which they produced their physiological and therapeutic effects. The recognition that these results were due to the development of heat within the tissues and organs showed that the high-frequency apparatus then in use for medical purposes was not suitable for the production of much heat. The modern diathermy apparatus has

since been evolved with this end in view—viz. the generation of the largest quantity of heat.

The development of heat within the tissues by the high-frequency current is an example of the other mode of action of electricity on the body—viz. by the production of *physical* effects. The physical effect is, in this case, the development of heat. In the case of the constant current and the currents of low-frequency oscillation, the effects are chemical or physico-chemical, and are brought about through the agency of ionic movement; in the case of the high-frequency current the effects are thermal and the ions are not moved.

Electricity can produce chemical and thermal effects in another way, quite different from that already described. The static breeze and high-frequency effluve will illustrate this. These forms of electrical application will be described later, but here it may be said that electricity at a very high potential is applied, so that if an air-gap is inserted between the electrode and the patient's body, the electricity, if directed from a pointed electrode, is able to bridge the gap in the form of a brush of nearly silent violet sparks, scarcely visible except in the dark. The application of this brush to the skin strongly stimulates the latter. The stimulation is due most probably to the *heating* of minute points of skin. Erythema is produced and even urticaria, if the application is strong. We are able, in one instance at any rate, to trace the physical, physiological and therapeutic results of the application of electricity. A patient suffers from headache as the result of low blood pressure. The application of the static breeze induces an erythema by the heating of minute points of the skin, and, as a physiological result of peripheral stimulation of the sensory nerves, there is a reflex rise of blood pressure and the headache disappears.

The passage of the brush discharge through the atmospheric gases causes the formation of ozone and nitrous and nitric acid. It is probable that these chemical products play a part, by virtue of their germicidal action, particularly in the treatment of some skin affections and infected ulcers.

The application of sparks from a static machine will frequently relieve pain in the region of muscles and fasciæ—*e.g.* the lumbar region—and the relief is sometimes instantaneous. The mode of action of electricity in such cases is, most probably, *mechanical.* The sudden powerful muscular wrench that accompanies the passage of a long spark breaks down adhesions. The static wave current also produces rhythmic muscular twitches, but less violent and more agreeable than those produced by the sparks. In bringing about relief, as it often does, in certain cases of chronic inflammation and congestion (*e.g.* traumatic synovitis, chronic neuritis, etc.), electricity, in the form of the static wave current, produces its results by physical (mechanical) methods. In applying the static wave current (the details will be given later) the body is alternately charged and discharged, the electricity suddenly escaping, during discharge, by way of an electrode placed in contact with the part requiring treatment. The therapeutic results are to be attributed, not directly to the electricity, but rather to its power of producing physical (mechanical) changes, the rhythmic twitching of the muscles inducing local acceleration of the circulation and mechanical removal of the effusion and loosening of adhesions.

It is not pretended that the account given in this chapter of the mode of action of electricity will explain, in every case, the way in which disease responds to electrical treatment. But if we look upon the cure or relief of disease by electrical methods as due, not directly

to the electricity itself, but rather to known chemical or physical changes that it produces, we are better able to judge whether electrical treatment is suitable for a case, and foresee the results that may be expected from its application.

CHAPTER II

THE CONSTANT CURRENT AND ITS MODIFICATIONS

THE various methods of applying electricity for the treatment of disease are, to all outward appearance, very dissimilar, as will be apparent to one who visits a modern electrical clinic. Yet in the greater number of cases an electrical current is applied, modified, in one way or another, and producing different physical and physiological effects. Each current may be derived, directly or indirectly, from one source—that is, the constant current. In this chapter it is proposed to describe the various modifications of the electrical current, taking the constant current as the starting-point.

THE CONSTANT CURRENT.—This current is so called because its strength does not vary and its direction of flow does not change. It is sometimes called the "continuous current," sometimes the "galvanic current." The constant current supplied on the mains in certain districts is generally called the "direct current," or, for short, DC.

The constant current may be obtained by *chemical* action, such, for example, as that which takes place in a battery cell or accumulator, or by *mechanical* action, as in the revolution of the armature of a dynamo.

This current can be accurately measured. When it is to be used for medical purposes we should know its voltage and its amperage. These are measured by the voltmeter and amperemeter respectively. The amperage expresses the *strength* of the current, or, more accurately, the quantity of electricity passing along the

circuit ; and the voltage is a measure of the *pressure* or *force* at which the electricity is impelled onwards.

A graphic representation of the constant current would be a horizontal straight line parallel to a base-line representing zero, and above it or below it according to the direction of the current, while the distance above it or below it would indicate either its pressure or its strength.

For medical purposes this is probably the most important and generally useful form of electrical current we have.

SIMPLE INTERRUPTED CURRENT.—This current flows always in the same direction, but the flow is intermittent,

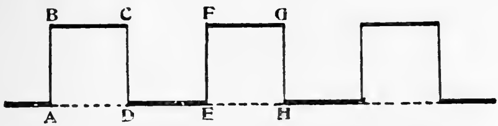


FIG. 3.—Graphic representation of simple interrupted current. The periods of current-flow and periods of no-flow are, here, of the same duration.

not continuous. There are alternate periods of flow and no-flow. During each period of flow the current strength is constant. At the end of this period the flow ceases *suddenly*, and the period of no-flow follows. At the end of the latter period the flow is *suddenly* resumed. A graphic record of a simple intermittent current is shown in Fig. 3. BC represents a period of flow, DE a succeeding period of no-flow. CD represents the sudden cessation of the current, EF its sudden resumption. The height of the line above the base-line would be proportioned to voltage or amperage ; the distance along the base-line would indicate time intervals.

Such interruptions of the current can be produced by alternately making and breaking the circuit along which the current flows. This can be effected by various mechanical devices. A simple make-and-break key can

be introduced into the circuit and operated by hand. A metronome can be adapted (Fig. 4), so as to produce regular and even interruptions. The swinging arm bears a horizontal wire, to each end of which is fixed a short vertical wire. Another vertical wire of equal length is fixed to the centre of the horizontal piece. When the arm of the metronome swings to and fro, the horizontal wire moves with it, and the vertical wires at the extremity of the latter rise and fall. Three small cups of mercury are fitted to the metronome, and so arranged that as the vertical wires fall and rise they dip into and rise out of the mercury in the cups. The central vertical wire does not rise or fall, but stays permanently immersed.

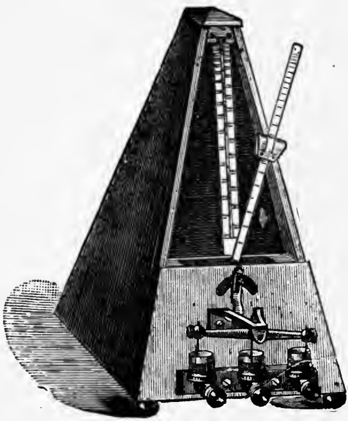


Fig. 4.—Metronome Interrupter

The vertical wires that dip into the mercury should be made of silver. A terminal is connected to each cup. To use the metronome as a current interrupter, one end of the wire conveying the current is attached to the central cup, the other end to one of the end cups. When the wire rises out of the mercury the current is interrupted. The number of interruptions per minute will depend upon the rate of swing of the metronome. The time the current flows between each interruption depends upon the rate of swing of the metronome and the depth to which the wire dips into the mercury. The metronome can be used to interrupt two currents alternately. Of the wires conducting the second current one is connected

to the other end cup, the other wire to the central cup.

The metronome interrupter may be used when regular interruptions of a current are desired without accurate measure of their duration. It is used in the process of muscle-testing by the condenser method, and in some forms of electrical treatment.

Another device for procuring simple interruption of the constant current is Leduc's mechanical interrupter. By means of this instrument the current may be interrupted as frequently as desired, and the periods of flow and of interruption may be varied and accurately measured.

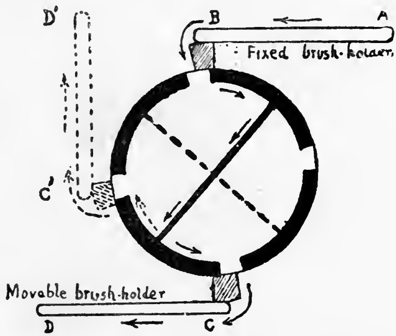


FIG. 5.—Plan of commutator of Leduc. When the current flows from the fixed brush-holder AB to the movable brush-holder in the position CD, the period of current-flow is the longest and of no-flow the shortest.

When the movable brush-holder is in the position C′D′, the period of current-flow is the shortest and of no-flow the longest.

Leduc's Mechanical Current Interrupter.—The essential part of the apparatus is a disc of insulating material mounted on the axle of a small motor and rotating with it (Fig. 5). Four metal strips are secured on the circumference, each being of equal length. They are placed symmetrically around the circumference. There is a small interval between consecutive strips. Diametrically opposite strips are in metallic connection with each other. Two contact brushes press against the circumference of the wheel, one being fixed, the other being movable through an arc of 90°, so that it may

touch the circumference at a point diametrically opposite the fixed brush, or at any point nearer, but not closer than one quarter of the circumference. The current can pass from one brush to the other, so long as the brushes are in contact with diametrically opposite pairs of discs. When the brushes are in the position shown in Fig. 5 (continuous lines), the current can flow from one strip to that opposite and continue to flow, when the strips are revolving, for the longest time possible. But when

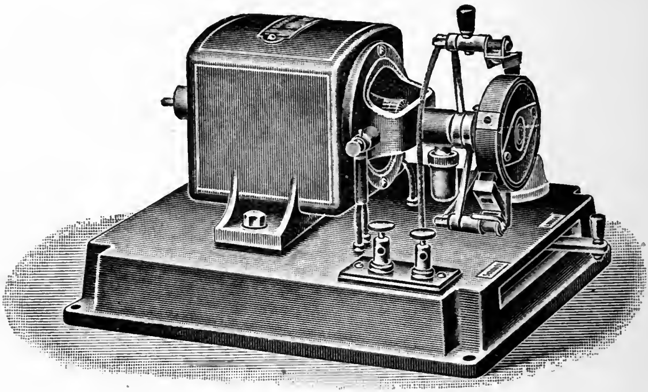


Fig. 6.—Leduc's Mechanical Interrupter

the movable brush has been moved round through 90° the current can flow only for the shortest time. In the first position the current flows for the longest time and the period of no-flow is the shortest. In the second position the period of flow is the shortest and that of no-flow is the longest. Intermediate positions of the brush give other periods of flow and no-flow. Increase of the length of the time of current-flow shortens the period of no-flow, and vice versa. The number of interruptions of the current depends upon the speed of revolution of the disc. The number of revolutions per second can

be indicated by a speed indicator. Increase of the speed of the interrupter will shorten the periods both of flow and no-flow.

By means of this current interrupter it is possible to vary the number of interruptions and measure the duration of the period of flow of the current, and the period of no-flow. The interrupter is shown in Fig. 6.

SIMPLE ALTERNATING CURRENT.—This current differs from the simple interrupted current in that it flows, during successive periods, in opposite directions. A graphic

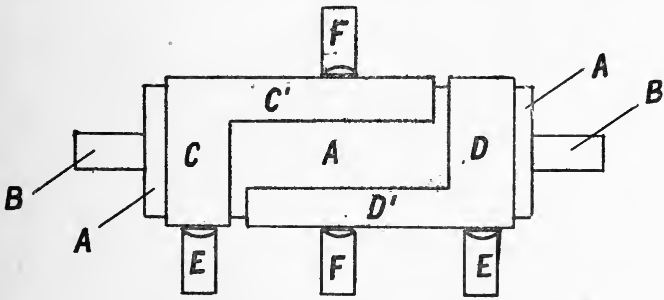


FIG. 7.—Ruhmkorff's Commutator

record of such a current is shown in Fig. 8. Between the successive periods of current-flow there are periods of rest, so that the current is *intermittent* as well as alternating. The simple alternating current may be obtained from the constant current by means of the device known as a Ruhmkorff's commutator. This is often fitted to galvanic batteries and induction coils for the purpose of reversing the direction of the current when desired. If it is attached to the revolving axle of a motor, the direction is periodically reversed at a rate depending on the speed of revolution of the motor, so that a simple alternating current is provided.

The Ruhmkorff commutator (Fig. 7) consists of a

cylinder of hard rubber, A, mounted on a spindle, B so as to revolve freely. On each end of the cylinder are fixed metal bands, C and D, and from one side of each band the metal extends for about two-thirds the length of the cylinder, in the form of cheeks C' and D', but not so far as to come into contact with the band at the opposite end. The cheeks C' and D' are usually made to embrace about one-fourth the circumference of the cylinder and are so fixed as to be exactly opposite each other. Four metal springs are now required. A pair, EE, is mounted one at each end of the cylinder, so as to press on the metal

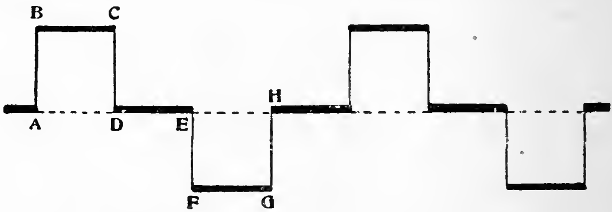


FIG. 8.—Graphic representation of a simple interrupted and alternating current. The periods of current-flow are here equal to the periods of no-flow.

bands, C and D. The other two, FF, are mounted on opposite sides of the cylinder at its middle, so as to touch the cheeks, C' and D', as the cylinder is revolved. The wires from the battery or other source of constant current are connected to the springs, EE, and the current led off by wires joined to the springs, FF. It will be seen that the direction of flow of a current in a wire joining the springs FF will be reversed each time the cylinder is rotated through half a revolution, and if the rotation is kept up the wire will be traversed by a simple alternating current. Such a current is graphically represented in Fig. 8. When the space between the metal cheeks is equal to the width of the cheeks, each period of flow of the current is followed by a period of rest of equal

duration. This period of rest can be increased or diminished by varying the width of the metal cheeks. A commutator for practical use is made so as to give from four to eight or more cycles per revolution, and so obviate the necessity for driving it at very high speed. The principle of its construction is the same as the one here described.

SINUSOIDAL CURRENT.—This current is supplied on the main in certain districts under the name "alternating

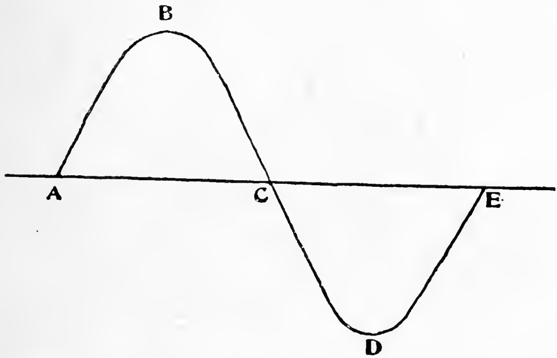


FIG. 9.—Graphic representation of a sinusoidal current—one complete phase.

current." It is a very useful current for many medical purposes. It can be taken direct from the main where the supply is an alternating current; where the supply is a constant (direct) current, the latter can be readily converted into a sinusoidal current by a motor transformer. To understand the way in which a sinusoidal alternating current is generated requires some knowledge of the mechanism of dynamos. This is briefly described on page 289. The sinusoidal current is an alternating current, but it differs from the simple alternating current just described, in that its rise from zero to

maximum and its fall from maximum to zero is gradual, not sudden. Further, on reaching zero, there is no period of intermission, but a second rise to maximum and fall to zero in the opposite direction. A graphic representation of a sinusoidal current is shown in Fig. 9. From A to B the current is rising to its maximum ; from B to C it is falling to zero ; from C to D it is rising to a maximum again, but the current is flowing in an opposite direction ; from D to E it is falling again to zero. ABCDE represents a complete cycle or phase. The

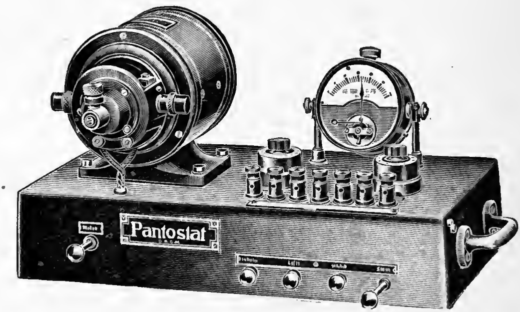


FIG. 10

" periodicity " of the current refers to the number of these complete cycles per second. If the current has a periodicity of 100, there are 100 of these cycles each second. From A to E the time interval would be $\frac{1}{100}$th second ; from A to C $\frac{1}{200}$th second. The height of the curve above the base-line at any spot is proportioned to the voltage or amperage.

The alternating current supplied on the main is generated at the power station by a dynamo. When the direct current is supplied on the mains, or when it can be obtained from a battery of accumulators, a sinusoidal current may be readily obtained by means of a motor transformer. Makers of electro-medical apparatus now

put on the market different patterns of so-called "universal" apparatus, sold under the trade names of "Pantostat," "Multostat," "Polystat," etc., and these convert constant into alternating sinusoidal currents. Such instruments are now largely used, and one pattern is illustrated in Fig. 10.

Slow Sinusoidal Currents.—The alternating currents on the mains have a periodicity not higher than 100 and not lower than 25. If there are fewer than 25 complete cycles per second (*i.e.* 50 reversals per second), lamps that are illuminated by such a current will not give a steady light. Sinusoidal currents of a lower periodicity are sometimes used in medicine, and Dr Reginald Morton has recommended the use of currents with a periodicity as low as 1·7—that is, in each second there are 1·7 cycles. The duration of each cycle would then be very nearly 0·6 seconds.

A slow sinusoidal current may be obtained from a motor transformer that is made to revolve slowly. This method is, however, very wasteful of current. A better method is to use a rhythmic reverser, such as that of Ewing. This is shown in plan in Fig. 11. The following description is taken from Dr Lewis Jones:—

"An insulating drum of ebonite is revolved in a glass cylindrical vessel of water which it nearly fills. There are metallic armatures, *CD*, inside the vessel at opposite ends of a diameter. Corresponding armatures, *A* and *B*, are fixed to the ebonite drum. If a difference of potential be maintained between *C* and *D*, as indicated by the signs + and −, there will be a flow of current from *A* to *B* through a conducting circuit joining these points, when the drum is in the position shown in the figure, and if the drum is turned round through 180° there will be a flow from *B* to *A* as the positions of *A* and *B* relative to the armatures *C* and *D* will have been reversed. Thus by

rotating the ebonite drum a sinusoidal current will be set up in the circuit *A B*. It will reach its maximum when the armatures *A* and *B* are close to *C* and *D* and will be at zero when they occupy the positions at right angles to this. To utilise the current in the circuit *A B* it must be collected by means of rings and brushes very

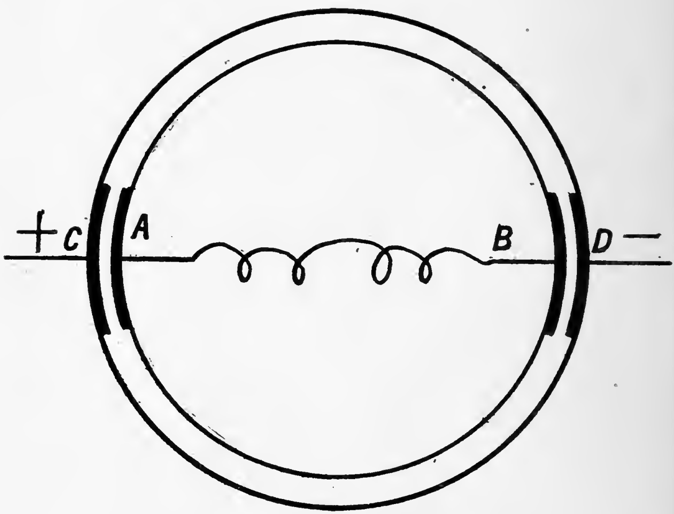


FIG. 11.—Plan of Ewing's Rhythmic Reverser

much in the way used with an alternating current dynamo."

FARADIC CURRENT.—This is the current that is obtained from the induction coil. The induction coil does not actually generate the current, but transforms the current of the battery attached to it. The latter is a constant current of low voltage. The coil transforms it into one of much higher voltage with corresponding diminution of amperage, and at the same time makes it intermittent and alternating. A graphic record of such a current is

shown in Fig. 13. It may seem unnecessary to the student to consider the matter of the output of induction coils, but the subject is important, as a clear understanding of it will show why it is that some medical coils produce painful and disagreeable results when used for treatment, and will show why the induction coil is not the most suitable instrument to employ when accurate results are desired in the investigation of the reactions of muscle and the physiological response of excitable tissues.

Before describing the meaning of the curve shown in Fig. 13 an account of the induction coil will first be given.

The induction coil is probably the best known electrical device in use by medical men and others. It is very inexpensive, especially in its simplest forms, and for stimulating living tissues it may be quite efficient. From the fact that it lends itself very readily to great variation in constructional detail, without seriously interfering with its working qualities, few instruments have been subjected to such extensive modifications—and though much ingenuity has been expended on it, it is doubtful if any substantial improvement has resulted.

Notwithstanding its complicated appearance, especially to the uninitiated, the induction coil is really a very simple appliance. Its essential parts are shown in Fig. 12.

A is an iron core—usually made up of a bundle of soft iron wires—around which is wound a comparatively few turns of fairly coarse wire: this is the *primary* coil. In all cases the wire used for winding coils is covered with silk or cotton for purposes of insulation. Opposite one end of the core is an iron block, *B*, which is secured to the end of a metal spring, *C*. A screw, *D*, is mounted so that its point comes opposite about the middle of the metal spring. The end of the screw and that part of the spring

with which it comes into contact are both faced with platinum. One end of the primary coil is connected with one pole of the battery, *E*—the other is connected to the spring, *C*. The other pole of the battery is connected to the screw, *D*.

Around the primary coil, but quite disconnected from it, is another coil of much finer wire and wound in very many more turns. This is the secondary coil. It is not shown in Fig. 12.

The secondary coil generally consists of a large number of turns of fine wire. It is not directly connected in any

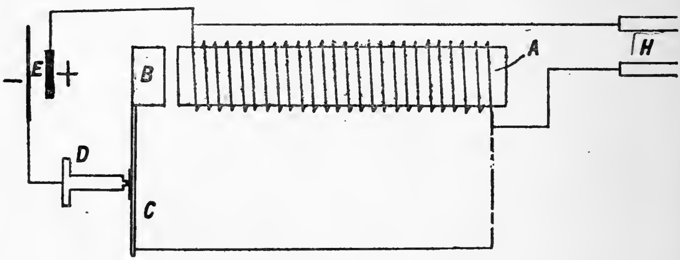


FIG. 12

way with the primary, but is wound on a bobbin, the hole through the centre of which is large enough to slide over the completed primary coil. By so doing the secondary is brought more or less into the magnetic field of the primary, and the electro-motive forces in it thereby adjusted. The secondary has from five to fifteen times the number of turns of the primary, for which it is made. The average proportion of primary turns to secondary turns is 1 : 10.

The course of the current can be easily traced from the battery to the primary coil, from this to the spring, *C*, thence through the platinum contacts to the screw, *D*, and so back to the battery. The current passing round the primary coil, the latter becomes, with the iron core,

an electro-magnet. It thus attracts the iron block, *B*, and in drawing the latter towards itself pulls the spring, *C*, away from the point of the screw, *D*. Immediately this happens the circuit is broken and the flow of current from the battery ceases. The core thus loses its magnetism, and the iron block no longer attracted, the spring, *C*, by its own elasticity flies back until it is stopped by the point of the screw, *D*. The circuit is thus again closed and the above-mentioned changes are repeated.

We may now consider the events that take place in the primary and secondary coils. Since the vibrating spring continually makes and breaks the primary circuit, the current flowing in this circuit (the primary current) is interrupted or intermittent. Further, at "make" and also at "break," an extra current is induced, not only in the primary circuit (the primary induced current), but also in the secondary circuit (the secondary induced current). These induced currents are of momentary duration. They may be taken in order :

1. *At "Make" of the Primary Circuit.*—The battery current flows around this circuit, but at the same time a new current of momentary duration is induced in the same circuit ,and it flows (as mentioned in Chapter XV., p. 287, under Self-Induction) in the opposite direction, impeding it and slowing its rate of rise to its maximum. This is shown in Fig. 13, *a* to *b*. It indicates the slow rise of the current in the primary to maximum. As a result of this impeded rise, the current that it induces in the secondary coil is of correspondingly long duration and does not reach so high a voltage (see Fig. 13, curve from *A* to *B*).

2. *At "Break" of the Primary Circuit.*—At the moment the primary circuit is interrupted the battery current ceases to flow, and at the same time an extra current is induced in the same circuit ; it flows in the *same* direction as the battery current, and therefore the induced current

is not impeded, but increased, and the cessation of the current in the primary circuit is abrupt (Fig. 13, *b* to *c*). The abrupt cessation of the current in the primary induces in the secondary a current of brief duration, briefer than that of the current induced in the same coil at "make" and one at higher voltage (Fig. 13, *BCD*).

It is evident, then, that the faradic current is highly complex. Further than this, the graphic record of the

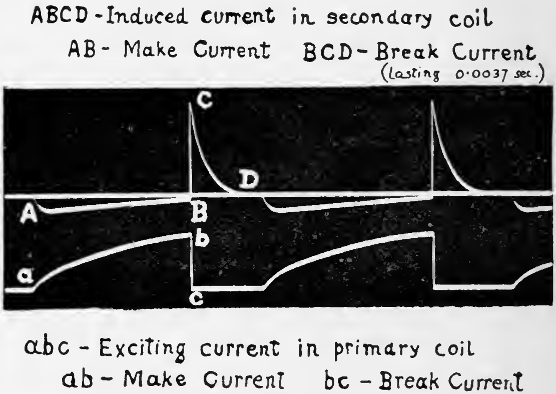


FIG. 13.—Graphic record of the primary and secondary currents of an induction coil.

[Adapted, by permission, from Jones' *Medical Electricity*. 6th Edition. H. K. Lewis & Co. Ltd., London.

output of induction coils varies greatly in coils of different design. The output depends on the length of wire in the primary and secondary coils, the presence or absence of an iron core, the design of the vibrating spring, the method of regulating the output, etc. The output may also vary in the *same* coil from time to time, according to the adjustment of the hammer, etc. We may therefore speak, not of a faradic current, but of varieties of faradic current. Any type of medical coil will give a current that will stimulate the tissues, but few will give a current

that will stimulate them painlessly. The question of the output of induction coils is a subject of much importance, both from the point of view of electrical treatment, and also the testing of the reactions of muscle and nerve. The first of these may be considered here; the second will receive attention in the chapter on the testing of electrical reactions.

Motor nerves and muscles will respond to currents of very brief duration. Sensory nerves, however, require currents of longer duration. The current that is provided by an induction coil should last, during each period

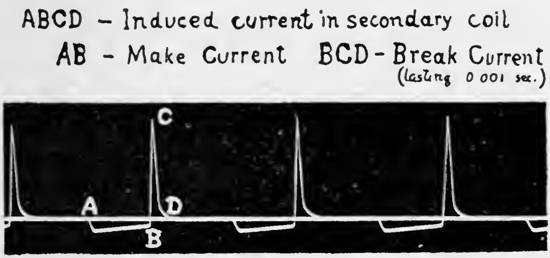


FIG. 14.—Graphic record of the secondary current from a well-designed coil.

[Adapted, by permission, from Jones' *Medical Electricity*. 6th Edition. H. K. Lewis & Co. Ltd., London.

of flow, the briefest possible time, so that muscles and motor nerves may be stimulated, and not the sensory nerves. A coil giving a record like that shown in Fig. 13 would produce painful contractions of muscle, because the secondary current flows for periods that are long enough to stimulate sensory nerves. Many other coils give currents that produce the same effect. A coil that is most suitable for medical treatment is one that produces the most vigorous contractions without disagreeable sensation. This requirement will be fulfilled if the induced current in the secondary at "break" is of the

shortest possible duration, and that at "make" being of insufficient strength to cause skin sensation or muscular contraction. A coil giving a graphic record like that shown in Fig. 14 would give the most agreeable and painless contraction of the muscles. The records in Figs. 13 and 14 are on the same scale. The record of the secondary current is given in Fig. 14 (not of the primary), and it will be seen that the duration of the current at "break" BCD is very brief ($\frac{1}{1000}$ second); that at "make" being of

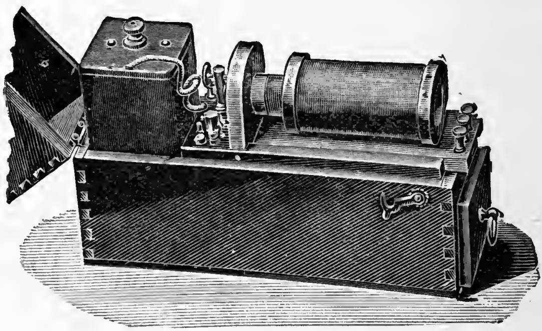


FIG. 15

insufficient intensity to cause perceptible stimulation. An electrical stimulus or impulse is produced each time the current at "break" flows. The number of these impulses per second depends on the rate of vibration of the spring. In the record shown the number was nearly 100 per second. Such a coil (Fig. 15) was designed by Lewis Jones, and the oscillographic record shown in Fig. 14 was obtained from one of this design. It is a valuable coil for use in medical practice, as the current will evoke strong muscular contractions without disagreeable sensation. It is enclosed in a case containing a dry cell and is portable. The primary circuit is completed and interrupted by a spring vibrating in a horizontal plane and actuated by the iron core within the primary coil. This core is not

movable. The secondary coil can be made to slide as a sledge over the primary coil. The current that is applied to the patient is taken from the secondary coil and is regulated by sliding the secondary over the primary. Three binding screws are connected to the secondary winding. From two of these the current from only one-third of the length of the secondary wire is taken. This

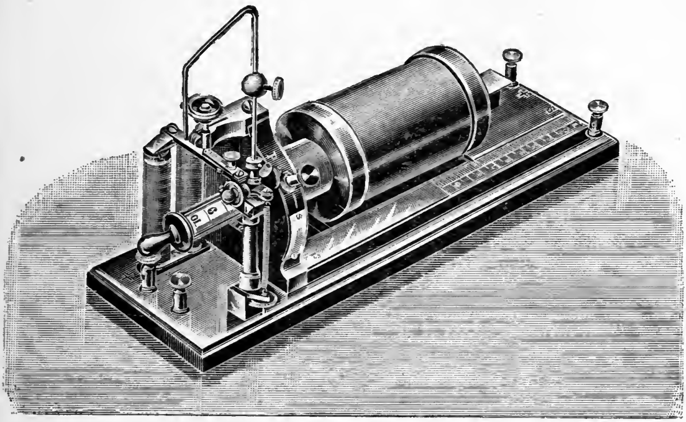


FIG. 16.—Sledge Coil

current is of lower voltage and is the most suitable when it is to be applied to the body through the damp skin by way of moistened pads, so as to lower the resistance. From another pair of binding screws the current from the whole length of the secondary is taken. The current is of higher voltage and is the one to be chosen when it is to be led through the higher resistance of dry skin.

There are many other designs of medical coils on the market. The requirement of a coil that is to be used for medical purposes is the power to produce strong contraction without pain. The readiest test is the sensation produced on one's own cheek, applying the current

through damp pads. The most accurate test is furnished by the graphic record given by the oscillograph.

Induction coils fitted with separate electro-magnets for working the vibrating spring produce irregular and uneven impulses and disagreeable sensory stimulation.

Many types of coil are made. Some of them are provided with an extra pair of terminals, so that either the primary or the secondary induced current can be applied to the patient. In Fig. 12, *H* represents the handles that lead the primary induced current to the patient. The primary current is regulated by sliding a brass tube over the iron core. Other coils have an arrangement in the form of a bent wire and a sliding ball (Fig. 16) fixed to the hammer, for the purpose of regulating the rate of vibration of the latter.

The question of the output of induction coils has been considered at length, because this form of electrical instrument is so widely used for so many medical purposes, and is not always of correct design. The best test of a coil for medical and physiological purposes is furnished by an oscillographic record.

The high-frequency and diathermy currents and the static wave and static induced currents will be described later, in the chapters dealing with these forms of electrical application.

CHAPTER III

SOURCES OF ELECTRICAL SUPPLY

When it has been decided to make use of electricity for the treatment of disease, the first practical question which arises is that of supply. There are different sources of supply and the selection will depend on what is available and most convenient. In almost all the applications of electricity for medical purposes, a current of one or another kind is used, and the current which constitutes the source of supply may require modification according as it is used either for direct application to the body or for the generation of other kinds of currents, or for other purposes. There are the following sources of supply:

1. The Street Mains.
2. Cells and Accumulators.
3. Dynamo and Driving Plant (private installation).

Each of these has its advantages and limitations. These will be set forth in the present chapter, together with the methods of modifying them so as to render them suitable for different purposes. For the generation of static electricity an influence machine is required, with an electric motor or gas or oil engine to drive it.

Current from the Main—The town supply that is distributed along the street mains and taken into many of the houses is the most convenient and economical source. The current is in some towns and districts a *direct* current (DC.)—*i.e.* its direction is unvarying. In others it is an *alternating* current (AC.)—that is, its direction is periodically reversing. The voltage at

which it is supplied is not always the same in different towns; in some it may be 100, in others 200 or 250. And in the case of the alternating current the frequency of the alternation differs in different towns. It is therefore necessary to find out with regard to the town current whether it is a direct or an alternating current, the voltage at which it is supplied, and the frequency of

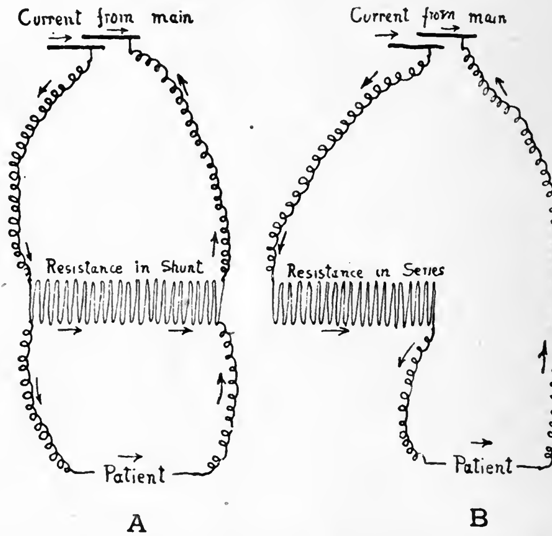


FIG. 17.—Current derived from main with resistance *in shunt* (A), *in series* (B).

the alternation when the town supply is an alternating current. These particulars are published each year in the January number of *The Electrician*.

The Use of the Direct Current from the Main.—The direct current is the most generally useful for medical work. The voltage at which it is supplied is in some districts 100; in others it may be as high as 250. The current that is taken to the lamp-holders and plugs has a strength

up to 5 amperes. Such a current has too high a voltage and amperage for direct application to the body, and it must therefore be reduced. The simplest and least expensive method of reducing its voltage and amperage is to insert a sufficiently high resistance. This resistance could be inserted *in series* with the patient, in which case the patient and the resistance would both be in the same circuit, and the current would traverse each in turn (Fig. 17, B). Such an arrangement is unsatisfactory, and the usual plan is to arrange the resistance

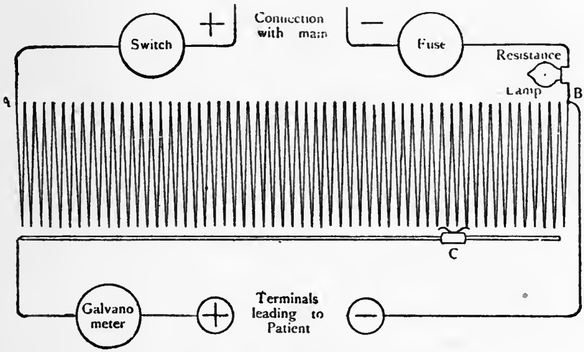


FIG. 18.—Plan of Shunt Resistance

in shunt. In this case the patient and the resistance are in separate circuits, and the current traverses each simultaneously (Fig. 17, A), the amount passing through each depending on their relative resistances. The resistance in the patient's circuit can be varied by including in the same circuit a varying length of the shunt resistance. This can be effected by connecting one of the wires leading to the patient—not to the end of the shunt resistance, but to a point a varying distance along it. With such an arrangement, part of the shunt resistance is in series with the patient.

Fig. 18 is a diagram showing the necessary arrange-

ment. The fine wire coil, from A to B, and the lamp at B constitute the shunt resistance. If we trace out the connections we see that the current comes in from the main at the positive terminal to the switch. When the switch is turned on the current flows through the fine resistance wire from A to B, then through a lamp and safety fuse to the negative terminal of the main. It also flows, when the patient is connected, along part of the length of the fine wire to the slider, C (this can be moved to the right or to the left), then through the galvanometer and through the patient back to the other circuit at B. The strength of current that passes along these two circuits will depend upon their relative resistances. The resistance of the circuit containing the fine wire and the lamp is constant, that of the other circuit containing the patient will depend upon the length of resistance wire between A and the slider, C.

On the + side of the connection with the main (Fig. 18) the voltage is at the maximum supplied on the main ; on the – side of the connection it has fallen to zero. The fall takes place gradually and evenly along the resistance from A to B. A further fall takes place in the lamp at B, and zero is reached on the – side of the fuse. From A to B the fall is even—there is a "slope of potential," as it is called.

If we take a sensitive volt-meter and connect one terminal to B, and having attached a piece of wire to the other terminal of the volt-meter, draw the free end of this wire across the turns of the resistance from B to A, we will find that we can get any voltage we desire from zero up to the highest given by the instrument—this will be from 50 to 80, depending on the resistance of the lamp at B.

Now it will be seen on reference to Fig. 18 that the patient is connected in the same way as the volt-meter. One of the terminals that lead to the patient is connected

to B, the other is connected with the slider, C, which can be moved along the resistance coil, AB, and in contact with it. This slider, C, is mounted on a metal rod that is placed parallel to the resistance coil and at such a distance from it that its springs are always in contact with it. The voltage of the current that passes to the patient can therefore be varied between zero and maximum by sliding, C, along the resistance coil from B to A. When the slider is at B, the terminals that lead to the patient will be in connection with the same region of the resistance coil, and there will be no difference of potential between the terminals, and no current will pass to the patient. On moving the slider farther and farther away from B towards A, the voltage between the terminals will rise higher and higher, and more and more current will pass to the patient. Its value is indicated by the milliampere-meter placed in the same circuit with the patient.

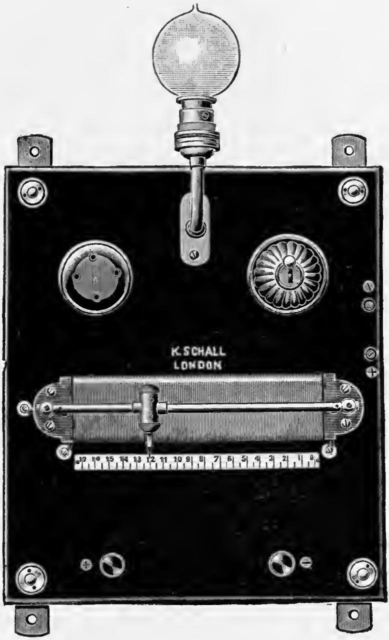


FIG. 19.—Shunt Resistance

Fig. 19 is an illustration of the actual apparatus the plan of which has been described. The various parts are mounted on a board that can be fixed permanently

to the wall. At the top are mounted the lamp, switch and safety fuse. Underneath is the resistance coil. In front of this is the slider which can be moved from side to side over its surface. The scale below the resistance coil serves to indicate the position to which the slider has been moved on any occasion. At the bottom of the

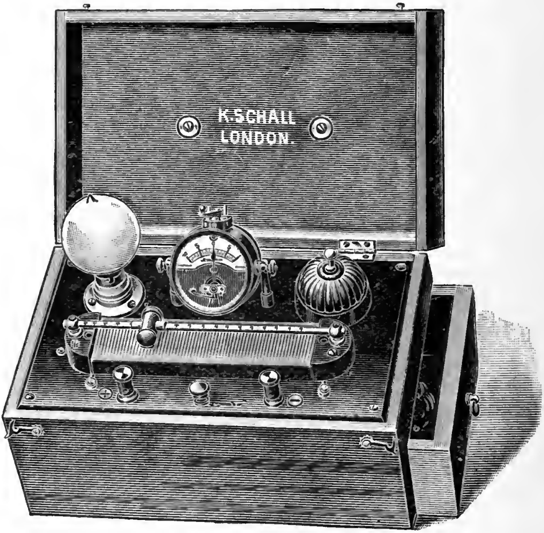


FIG. 20

board are two terminals to which will be fixed the cables that lead the current to the patient. A milliampere-meter is not attached to this board.

Fig. 20 shows a similar apparatus, contained in a box, so that it is portable.

The current which is given by the apparatus described may be varied, by adjusting the position of the slider, between a fraction of a milliampere and 300 milliamperes, so that it is suitable for all purposes for which a constant current has to be applied direct to the body—

viz. ionisation, electrolysis, etc. Its voltage can be varied between zero and a maximum of about 80.

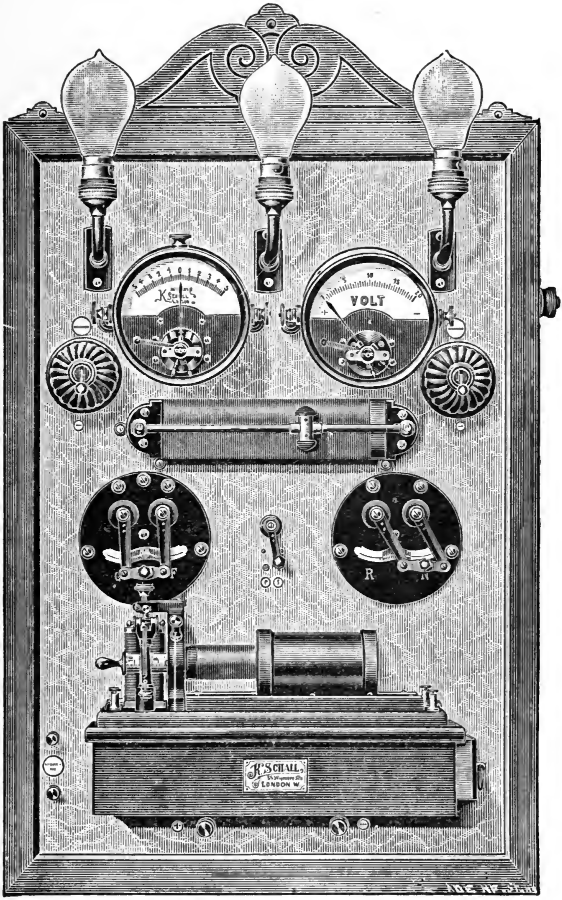


FIG. 21.—Galvano-faradic Outfit

The current that is taken by the apparatus from the main is not large, and it may be taken with safety from a lamp-holder or wall plug.

A more elaborate switch-board is shown in Fig. 21. A volt-meter and a milliampere-meter are fitted so that the voltage and amperage of the direct current that is supplied to the patient can be measured. There is also a reverser, so that the direction of the current may be altered as desired. An induction coil is also fitted. It is worked by the current from the main, suitably reduced by the lamp shown on the top left-hand corner of the board. Either the faradic or the direct current can be led to the two binding screws shown at the bottom of the board, and thence to the patient, according to the adjustment of the de Watteville key shown on the left side of the board just above the induction coil.

The volt-meter is not essential, but it is very convenient to have. It shows the difference of potential between the electrodes applied to the patient, and by its use rough approximations of the resistance between the electrodes can be arrived at by taking the reading in volts and milliamperes and working it out by Ohm's law.

The direct current from the main may also be used for heating the cautery, but here again it requires modification. A cautery has a very low resistance, a small fraction of an ohm, which is very much lower than that of the body. Therefore a much lower voltage is required. Two volts will usually be sufficient, while that of the main current (100 to 250) is far too high. On the other hand, the cautery requires a high amperage (say 12 to 18), which is higher than that of the current supplied to houses for lighting purposes and very much higher than that of the current given by the apparatus described above (viz. a maximum of 300 milliamperes, or 0·3 ampere). Neither this apparatus nor the unaltered main current are suitable for cautery. It is possible, however, to obtain a cautery current from the main by using an apparatus of the same type as that described, but modified in the following way. The shunt resistance

should be much lower, and should consist of fewer turns and of stouter wire. A lamp is not included in the circuit, as it would add too much resistance. A slider is fitted so as to move along the shunt resistance and so regulate the amount of current that is taken to the cautery. For finer regulation a rheostat (a variable resistance) is inserted between the slider and one of the terminals leading the current to the cautery. A plan of the device is shown in Fig. 21. It has the disadvantage of being very wasteful of current. For

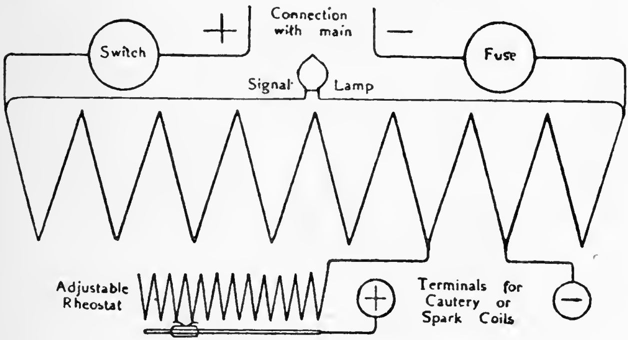


FIG. 22.—Shunt Resistance for Cautery

this reason a small lamp is inserted, as shown in the figure, to act as a signal that the current is flowing so that it may be turned off when it is no longer required. This lamp, it will be seen, is inserted *in shunt* with the resistance not *in series* with it, so that it will only take a very small proportion of the current.

Another disadvantage is that it cannot be connected to a lamp-holder or wall plug. It takes a very large current (because the shunt resistance is low and no lamp is included in series with it), and if it were connected to a lamp-holder or wall plug the safety fuse would melt and the current would be cut off. If the practitioner has

not heavy cables taken into his house from the street mains specially adapted for heavy currents, he will have to derive the cautery current from accumulators or from a machine known as a "motor generator" or "motor transformer." This is a combination of an electric motor and a dynamo or generator. The current from the main causes the revolution of the motor, which in its turn actuates the dynamo. The dynamo generates the new current and it can be wound so that this current has the voltage and amperage desired. The motor generator is illustrated and further described on p. 45.

For the illumination of surgical lamps like those fitted to the ophthalmoscope, cystoscope, etc., we require a current of lower amperage than for cautery, but higher voltage. If the lamp filament is long and thin it will have a higher resistance, and the current must be at higher voltage. Short, thick filaments have a lower resistance and require a lower voltage, but a higher amperage if it is to be raised to incandescence.

For quite small lamps the apparatus first described, for providing currents suitable for direct application to the body, may be used. For larger lamps, accumulators or a motor generator should be used. Or a suitable shunt resistance constructed on the same plan as that for cautery may be used. It must be seen that the current which it takes is not heavier than that for which the house cables are intended to carry.

The direct current from the main is also suitable for working the large induction coils used for the production of high-frequency currents and X-rays. These coils usually take more current than that carried by the cables passing to a lamp-holder, so that it is generally necessary to fit heavier cables.

For the diathermy machine the direct current is unsuitable. It must be converted into an alternating current. This is done by a motor transformer, and one

must be used that can provide an alternating current of at least 10 amperes at 100 volts. The current that is taken by this transformer is heavy and cannot be carried on the house cables. Specially heavy cables must be taken into the house from the street main, sufficient to carry 20 amperes.

The use of a shunt resistance for lowering the pressure of the main current is not unattended by risk. The risk lies in the possibility of accidental short-circuiting to earth and so obtaining a much larger proportion of the main current than is desired, or even the whole of it, with disagreeable or disastrous results. How this risk is possible will be explained on page 52, together with the precautions necessary for avoiding it. By using a motor generator this risk may be avoided. Manufacturers of electro-medical apparatus now make forms of so-called "universal" apparatus. Such apparatus contains a motor generator, and by its use it is possible to derive from the main constant and sinusoidal currents, and currents suitable for cautery and electric lamps. Different forms of "universal" apparatus are sold under the names of "Pantostat," "Polystat," "Multostat," according to the maker. A Pantostat is shown in Fig. 10. Mounted on the left side of the base is the motor generator. It is connected to a wall plug or lampholder. The constant current from the main causes the revolution of the motor, and two new currents, quite distinct and separate from the main current, are formed. (The principle of the motor generator is described on page 292.) Of these two new currents one is a constant current, suitable for direct application to the body, either through electrodes or by means of the bath. Since this current is on a circuit quite separate from the main circuit, risks of shocks are avoided, as short circuiting is impossible. The other current is an alternating current. This can be varied in strength and applied to

the body in the same way as the constant current. Or it can be taken to static transformers (contained in the base of the machine) and transformed into currents suitable for cautery and lamps. As with the constant current, there is the same freedom from the possibility of shocks through short-circuiting.

On the base of the machine are two switches and a milliampere-meter. One of the switches reverses the direction of the constant current. The other is for the purpose of leading either the constant current or the sinusoidal, or both together, to the patient or for cutting off all current. The continuous and sinusoidal currents are taken to the right-hand pair of terminals. The left-hand pair lead off the cautery current. The two middle pairs lead off the current for illuminating lamps, one pair for small lamps, the other for larger lamps. Five sliding rods can be pulled out from the base of the machine : one regulates the strength of the current passing to the motor ; the others regulate the strength of the currents for cautery and light, and the sinusoidal and constant currents.

The Use of the Alternating Current from the Main.— The voltage at which this current is supplied on the mains differs in various towns and districts. In some it is 100 ; in others it is as high as 250. The amperage of the current taken into the houses for lighting purposes is the same as for the direct current. The periodicity is not the same for every town. In some it is 25 ; in others it may be as high as 100.

The alternating current is very suitable for cautery heating and for lighting lamps, and for stimulation of the body. It is necessary for diathermy. It cannot be used for ionisation or electrolysis or for operating induction coils.

As with the direct current, the first requirement is the

reduction of the voltage and amperage when it is to be applied to the body. This may be done by a shunt resistance as described for the direct current, but a much more satisfactory way is to use a " static transformer." By means of this the current from the main and that passing to the patient are quite separate from each other, so that risks of shocks from short-circuiting are not possible. Regulation of the strength of the current passing to the patient can then be easily effected by inserting

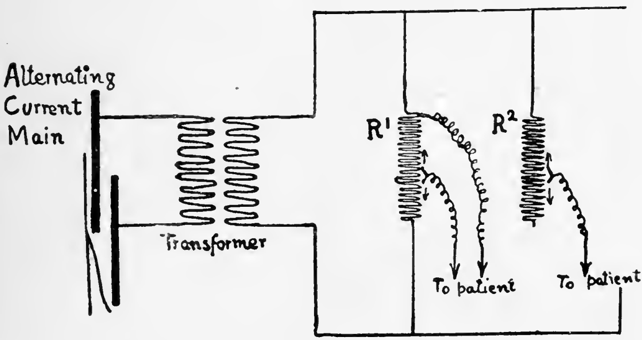


FIG. 23.—Scheme for derivation of current from alternating current main by way of a transformer, and regulation of current by means of a resistance either in shunt (R^1) or in series (R^2).

a shunt resistance or series resistance in circuit with the patient. A scheme of the arrangement is shown in Fig. 23.

A static transformer consists of a core of soft iron, around which are wound two separate coils of insulated wire. One of these coils is called the primary coil, the other the secondary. These coils form quite distinct and separate circuits. The alternating current from the main passes through the primary coil, and as it oscillates to and fro induces another alternating current in the secondary. It is not possible, with proper insulation, for the main current in the primary coil to get into the secondary

coil. The voltage and amperage of that induced in the secondary depends upon the number of turns of wire in this coil, as compared with the number of turns in the primary. If there are fewer turns in the secondary, the induced current will be of lower voltage and higher amperage (suitable for cautery and lamps) ; if there are more turns in the secondary than in the primary, the induced current will be of higher voltage and lower amperage. This transformer is called a *static* transformer, as it has no moving parts, unlike the *motor* transformer.

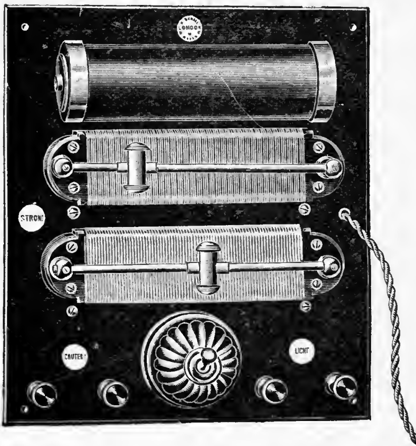


FIG. 24.—Transformer for Light and Cautery

A static transformer suitable for deriving a current for cautery and light is shown in Fig. 24. The transformer is fixed to the upper part of the board. The alternating current, taken from a lamp-holder or wall plug (the primary coil of the transformer takes a current of about 2 amperes), passes to the primary coil of the transformer. On the secondary coil is wound a smaller number of turns of wire so that a current of lower voltage and higher amperage (also alternating) is induced in it. This current which is suitable for heating cautery and has an amperage of about 18, is led to the two terminals on the bottom left-hand corner of the board.

There is another secondary coil also wound over the primary, and the number of turns is arranged so that a

current of about 2 amperes at 15 volts is induced in it. This current is suitable for lighting lamps. It is led to the terminals at the bottom right-hand corner of the board. The cautery current and the light current may be regulated according to the requirements of the instrument or lamp used. The regulation of each current is effected by a "rheostat" (a variable resistance). Each rheostat is made of a coil of resistance wire, and a variable length of it can be included in the circuit (in series) by altering the position of the slider. The upper rheostat is for the cautery current, the lower for light current. For both of these currents the voltage has been lowered. The transformer is therefore known as a "step-down" transformer.

A sinusoidal current suitable for use in electric baths can be also obtained from a static transformer. The secondary of the transformer is wound so that the voltage of the induced current is high enough to overcome the resistance of the baths in the circuit. Usually it has to be raised; the transformer is then a "step-up" transformer. Regulation of this induced current can be effected by means of a *shunt* resistance of the same kind as that used for lowering the voltage and amperage of the direct current from the main (described in the early part of this chapter) or by a series resistance. Another way of regulating the current is to lead it through a coil of wire, like the primary of an induction coil, and let it induce another current in a separate coil that can slide over the primary as a sledge (like the secondary of an induction coil). This last current is taken to the patient and its strength can readily be regulated by sliding the secondary over the primary.

By means of a motor the secondary can be made to slide backwards and forwards over the primary, and so produce rhythmic variation of the current supplied to the patient. A device of this kind, made by Gaiffe, of Paris,

has been in use in the electrical department at St Bartholomew's Hospital for some years, for supplying a sinusoidal current to three arm baths placed in series. It requires very little attention and there is no risk whatever in using it.

For the purpose of electrolysis, ionisation, etc., for which an alternating current cannot be used, some method must be adopted for converting the alternating into a constant (direct) current. This can be done by means of a motor generator adapted so as to work when supplied by an alternating current. "Universal" apparatus is made so as to take an alternating current, and it will then provide the currents that have been mentioned under the description of the Pantostat.

The direct current supplied by the Pantostat is not sufficiently strong for the operation of large induction coils for X-ray work or high frequency. For these purposes it is necessary to use a more powerful motor generator.

For operating the diathermy machine an alternating current is required, and the voltage of this current should be 100 and the amperage not less than 10. The cables that are fitted to a house for ordinary lighting purposes would not take a current of this strength. It is therefore necessary to introduce cables into the house that can take 20 amperes.

The alternating current cannot be used to charge accumulators on account of its repeated change of direction. There is a device known as the "Aluminium Rectifier" which will allow the passage of a current in one direction, but not in the other. If, therefore, it is included in the circuit of an alternating current, only those portions that pass in one direction will be allowed through, and the current will now flow only in one direction. It will, however, not be constant, but intermittent.

The rectified alternating current can be used for many purposes for which continuous currents are necessary. For charging accumulators some authorities consider it superior to constant current, and as a result of considerable experience the author is inclined to agree with this view. It will drive continuous current motors quite satisfactorily and can be adapted to operate large spark coils so as to give excellent results. It is not smooth enough for direct application to patients.

Rectifiers are of two kinds—chemical and mechanical.

Chemical rectifiers depend for their action on the peculiar property of aluminium in that it offers a very high resistance to the passage of a current when it is made the anode of an electrolytic cell, at the same time it offers no particular resistance when it becomes the kathode.

A rectifier may be made of a jar containing a saturated solution of ammonium phosphate in which are partially immersed, without touching, a rod of aluminium and another of iron. A current is able to pass through the solution from iron to aluminium, but not from the aluminium to the iron.

By means of a small cell of this kind an accumulator can be charged direct from the alternating main and left going all night, and in that way the battery kept charged and always ready for use. It is impossible for this rectifier to get out of order under ordinary circumstances, and it is quite independent of any temporary interruption of the main current. They are made of various sizes, the larger of which can be used for large sparks coils and for direct current motors, as well as for charging accumulators. What is known as the Nodon Valve is a rectifier constructed on this principle. These rectifiers have to be made very bulky when currents of any magnitude are passed through them, otherwise they become very hot.

Mechanical Rectifiers.—These are really motor transformers of which the motor part is constructed so that it can be worked by an alternating current. A direct current is then generated. The makers of "universal apparatus" construct types that can be operated by the alternating current. The direct current which they give is suitable for direct application to the body, in baths, or by means of ordinary electrodes. It is not sufficiently strong for the operation of large spark coils, such as are used for the production of X-rays. For this purpose larger motor transformers of the same kind must be used.

Dangers attending the Use of Currents derived from the Mains.—At this stage it will be well to point out the risks that are run when current derived from the main is used for medical treatment, and show how they arise and how they may be avoided.

In all cases where patients are being treated by means of electricity derived from the street mains, there are certain precautions which must be observed to prevent accident. On account of the voltage and amperage of the main current, it is always possible to give unpleasant, even dangerous, shocks. Even if such an accident should not be attended with serious results, it is very disconcerting to all concerned, and patients sometimes strongly resent even slight shocks if they have not been warned beforehand. Carelessness in this respect leads to loss of confidence on the part of the patient, and possibly even the loss of the patient.

To understand why it is possible to obtain shocks when the current from the main is used, even with a shunt resistance, attention must be paid to the way in which the current generated in the power station is distributed along the mains. A system of distribution known as the three-wire system comes from the generating station in the form of a three-wire cable. One of these is the

positive, another is the negative, and the third is neutral and acts as a common return to the others. All three are insulated from each other. The neutral is positive to the negative wire, and negative to the positive wire, and, by a rule of the Board of Trade, must be connected

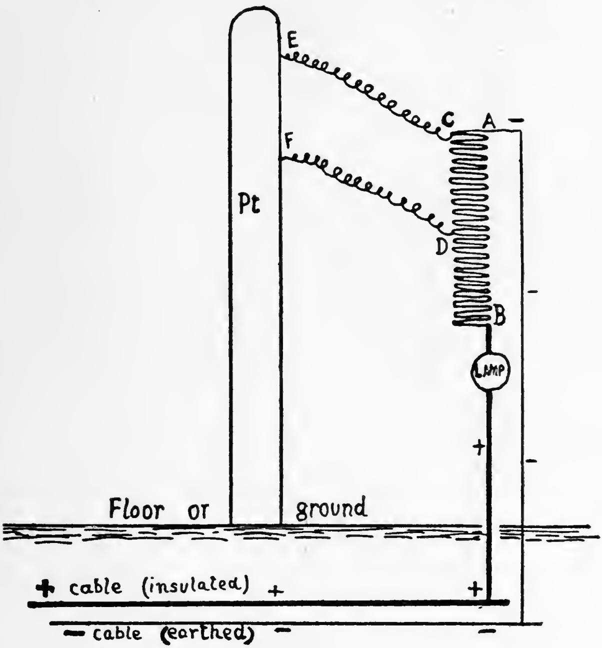


FIG. 25

to earth. Consumers are supplied from the neutral and one or other of the other two. The earth is a good conductor of electricity. Anything that is connected to earth by a conductor ("earthed" is the customary expression), such as metal water-pipes, radiators, electric-light fittings, streams of water coming from pipes (metal or rubber), stone floors, wooden floors when damp, is

therefore connected to one of the main cables (the neutral one). Now if the patient is in connection with the other cable he has only to touch any one of the objects named, or touch the operator, who is himself touching one, to get the current from the main through him. The same thing will happen if the patient has damp boots resting on a wet floor or on water-pipes or other earthed objects.

It is therefore necessary that a patient under treatment should be so disposed that no conductor connected to earth is within his reach. The floor should be quite dry, and, if it is made of wood or stone, should be covered with some non-conducting material, such as linoleum. It must not be forgotten that water containing substances in solution (and therefore a conductor) may drip out from the damp pads and moisten the floor, and make its way between adjacent pieces of the non-conducting material covering the floor, thereby establishing an earthed contact for the foot to touch.

In the diagram (Fig. 25) is shown a patient receiving treatment by a direct current taken from the main, with a shunt resistance interposed, as described in the early part of this chapter. Two of the main cables are seen under the ground, and one of these (the neutral) is connected to earth. Suppose that the first cable is positive, the neutral cable becomes negative to it. The + cable is insulated from everything. A shunt resistance, BA, and lamp are shown and are supposed to be in a room. When the main current is switched on it passes from the insulated + cable up into the room, through the lamp, then through the shunt resistance, BA, then back to the earthed negative cable. CDFE is the circuit that includes the patient (Pt.). Part of the current passes through this circuit. Let us suppose that the patient is earthed (touching a radiator or water-pipe or electric switch, or standing on a non-insulating stone floor, or a damped wooden floor ; or he

may be touched by a friend who is earthed). The current, instead of taking the path described, can travel through the lamp, along the shunt resistance as far as D, then to the patient at F, then through the patient to earth and the negative cable. But no shock will be felt, because

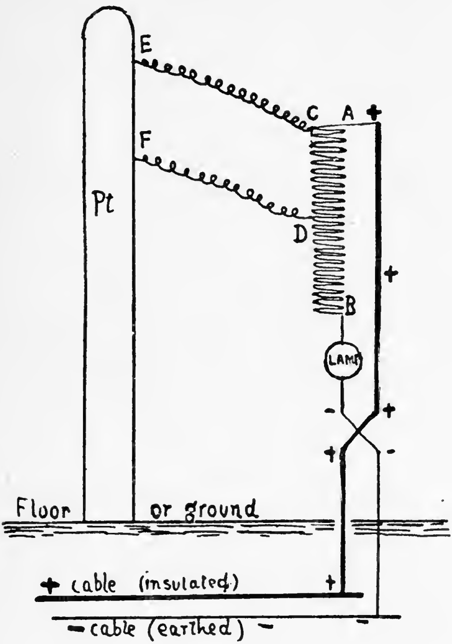


FIG. 26

the resistance of the patient is probably not less than that of the portion of the shunt resistance, DC, which the current has avoided. But when D is placed closer to B, a shock will probably be felt. Now suppose that the current from the main is taken to the shunt resistance in the opposite direction. This may readily be done by altering the position of the two-point plug that leads

the current to the shunt resistance. Reference to the diagram shown in Fig. 26 shows that a short circuit will be formed through the patient if he is earthed and he will then receive the full pressure of the current from the mains. The current will pass from the positive cable to A, along CE to the patient, pass right through his body to earth, missing out the entire length of the shunt resistance, AB, and the resistance of the lamp.

Such an accident could be prevented by making the plugs so that they can be fixed in only the correct position. It is safer to have two resistance lamps instead of one, and place the other on the other side of the shunt resistance, so that the current has to traverse it before entering the former at A. An additional precaution, which should always be taken, is to make the current pass through two lamps that are permanently in position on a switch-board on the wall before entering the other lamps and shunt resistance. It is always advisable to use two lamps, because if the filament fuses the metal may fall across and make a short circuit at the base of the lamp, and so cut out most of its resistance. If there is only one lamp, the sudden increase in the strength of the current passing through the shunt resistance and the patient would cause a shock. There is another possibility of accident, as the resistance wire may break, and if the breakage occurs between A and D (Fig. 25) the current must all traverse the patient to get back to the negative cable. The shock that the patient receives is not likely to be severe, unless there is a greater length of wire included between A and D. This risk may be almost completely avoided by using two shunt resistances connected in parallel, so that the current traverses both simultaneously.

If the precautions mentioned above are taken, the direct current from the main may be used for application to the body, either by means of pad electrodes or the

Schnee bath. Accidental shocks, though disagreeable, are never fatal, because the current is applied only to relatively small portions of the body. In the case of the full-length bath the case is different. Here the patient is quite devoid of any protection which a dry skin or clothing might otherwise afford him, and is also quite unable to help himself quickly when immersed in the water of the bath. If it is desired to apply the direct current from the main to a full-length bath, the precautions already mentioned have to be taken, and, in addition, the bath itself must be completely insulated from earth.

To thoroughly insulate the bath is practically impossible in the case of those already fixed, but it is quite feasible if the bath is installed with that end in view. The one at the London Hospital was done this way and is satisfactory. The bath itself is of porcelain. Large rubber pads about one inch thick are placed between the bath and the cement pedestals upon which it rests. Part of the waste-pipe consists of a length of rubber hose—leakage of current may occur here along the thin layer of water left in the pipe, but its resistance is high enough to prevent any such leakage worth troubling about. The water-pipes are kept clear of the bath and discharge from a point high up out of the reach of the patient.

The late Dr Lewis Jones considered that "no method which depends for its safety upon the maintenance of insulation from earth of a bath containing water is good enough to risk." If it is desired to use the direct current from the main in the full-length bath, the safest way is to use the motor transformer like that supplied on the "Pantostat," etc. Motor transformers that are used for this purpose must have the wire of the armature of the motor quite separate and perfectly insulated from that in which the direct current is generated.

At St Bartholomew's the direct current is not supplied

to any of the full-length baths, the alternating (sinusoidal) current being used instead. As explained before, the inclusion of a static transformer removes all risks of short circuits to earth. After the current has been switched on and regulated, the patient requires no further attention. There has been no accident or failure since the baths were first installed. Another advantage of this freedom from risk is that continued attention to the patient while in the bath is not necessary—an advantage which is specially to be considered in busy hospital practice.

Supply from Private Installation.—Where current from the main is not available some other source of supply must be sought.

If it is intended to use electricity more or less extensively, of course the best way is to install a dynamo and drive it by means of a gas, oil or steam engine, or even a water turbine, if such power is available. The current could be used direct, but it would be found more convenient to charge accumulators with it and use the current from them. In this way the engine need only be run for a few hours on two or three days a week, and the current will be available at all times. Where space is a consideration, a very compact little plant can be obtained, composed of a petrol engine, such as used on motor bicycles, coupled direct to a dynamo suitably designed for the purpose. A set to give 15 amperes at 60 volts meets most medical requirements in a private practice or small hospital, and runs very satisfactorily. In all cases the dynamo should be provided with slip rings, so that alternating current can be obtained when necessary.

While the upkeep of a small private plant as above indicated is not very costly, the initial outlay may prove an insurmountable obstacle. If there is a place in the

neighbourhood where cells can be charged, then accumulators should be used.

Supply from Accumulators.—The construction and mode of action of accumulators is described on page 270. Accumulators provide a current of low voltage and high amperage, and are therefore particularly suitable for heating cauteries and lighting lamps. They can be readily obtained, packed in portable cases. Two to four connected in series will be sufficient for cautery and light; and six will provide a current strong enough to work a spark coil as well. The strength of the current that is required can be adjusted by a rheostat attached to the case. The current from accumulators can be used for applications to the body, but as a higher voltage is necessary to overcome the resistance of the body, a number must be connected in series. The weight of such a battery would be very heavy; it is therefore more usual to use a battery of dry cells when a direct application of the current to the body is to be made. Such a battery is described in the next paragraph.

A dozen 4-volt batteries such as used for motor bicycles, could be arranged to meet most medical requirements by means of a multiple switch, which would put them all in parallel, for cautery or light, and all in series for direct application to the body—with a shunt resistance.

Another method of utilising the high pressure direct current mains is to charge an accumulator therefrom through a resistance and then use the accumulator independently. This system has many advantages for certain purposes. It enables one to keep a battery charged which can be taken about and used for cautery, light, or working an X-ray coil. With the direct current laid on, the charging of a battery is most simple. A special plug is provided which is fitted with a lamp-holder so that lamps of different resistance may be used.

From this plug runs a double flexible conductor. Having ascertained which one of these is positive it should be marked so as to avoid confusion in the future. This end must always be connected to the + terminal of the battery and the other one to the − terminal. A 16 c.p. lamp should be placed in the lamp-holder and the plug inserted. The accumulator may be connected up to the main when the day's work is done and left going all night when sufficient energy will have been stored up to last one or more days according to the demand made upon it.

As the resistance lamp used glows with almost its full candle power there is no reason why it should not be arranged to take the place of one of the lights regularly used in the house. In this way the charging of the accumulator costs practically nothing.

Supply from Primary Batteries.—If none of the sources previously mentioned are available, the supply may be obtained from primary batteries. Dry cells are now almost always used. Batteries of these cells packed away in wooden cases are now extensively used, and by reason of their portability, cleanliness and freedom from risk of shocks by short-circuiting to earth, are convenient for those for whom a main supply of current is not available. The cells will last for two years with average use before they require to be replaced by fresh ones.

Primary batteries of dry cells will provide a current suitable for application to the body, as for electrolysis, ionic mediation, etc., and for the lighting of *small* lamps. The amperage of the current is not sufficient for heating cauteries or driving spark coils for X-ray work or high frequency. For these purposes batteries of bichromate cells (page 272) are suitable. Such batteries can now be obtained in portable cases. They are heavier than the dry-cell batteries and require more frequent recharging,

although the owner can recharge them himself if he has a stock of potassium bichromate and sulphuric acid.

Portable Dry Cell Batteries.—These batteries can be obtained from any instrument-maker. The number of cells that they should contain will depend on the purpose

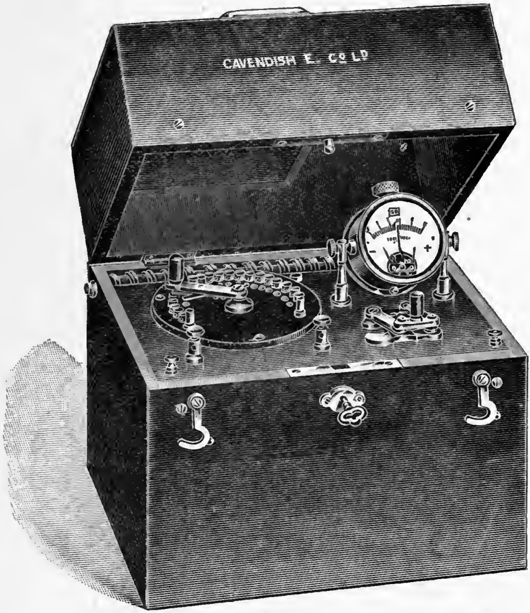


FIG. 27

for which the current is required. For application of the current to the mucous membranes, 8 to 12 will be enough. For application to the skin, a larger number will be required. A battery of 32 will be suitable for almost all cases for which the direct application of the galvanic current to the body is desired. Fig. 27 shows such a battery. The case also contains a milliamperemeter, a current reverser, and a current collector. By

means of the latter, the strength of the current can be increased or diminished by including a larger or smaller number of cells in the circuit.

It consists of a metal arm pivoted in the centre of a disc upon which are arranged as many studs as there are cells in the battery. These studs are insulated from each other and arranged in a circle, so that the metal arm as it is rotated comes successively into contact with the

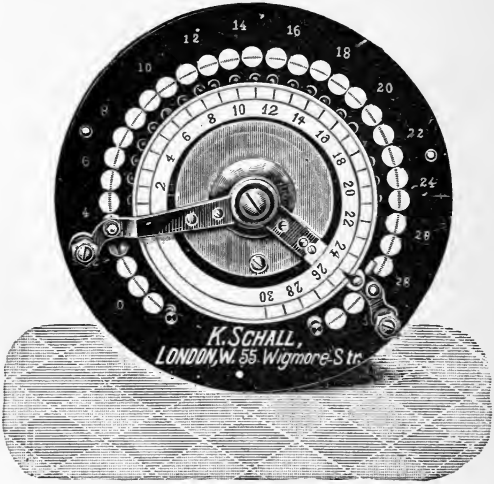


FIG. 28

studs. The cells are all joined up in series, but a wire has to be brought from each junction to one of the studs, to which they are joined in regular order. In this arrangement the first cells are always used, those at the other end are used only when the strongest current is required. Hence the first cells are exhausted soonest, and then they form a useless resistance for the other cells to traverse.

The double collector, Fig. 28, is an improvement on

this, enabling any group of cells to be used at will. It has two cranks mounted on the same axis but insulated from each other. One crank is connected to the positive and the other to the negative terminal. An index is fitted to one of the cranks which shows at a glance the number of cells in action at any moment. Next to the shunt resistance it is the best method of controlling the current from a battery of this kind.

The current collector does not allow absolutely even regulation of the current. The current increases step by step as cell after cell is taken into the circuit; these sudden increases cause pain when sensitive parts, such as the alveoli of the teeth, are subjected to them, but are not felt when the current is passed through the skin in less sensitive parts.

A shunt resistance allows the most perfect regulation of the strength of the current. The cells are joined together in series and the current from the total number is passed through a rheostat. The current for the body is shunted off from the rheostat and its strength is regulated by moving a slider along the latter, the method being the same as that adopted for the regulation of the direct current from the main.

CHAPTER IV

THE BODY AS A CONDUCTOR OF ELECTRICITY

Resistance of the Body.—When an electric current traverses the body, it encounters its chief resistance in its passage through the skin, the soft tissues and organs underneath opposing its flow to a much lesser degree. The resistance of the skin varies within wide limits, while that of the underlying parts is relatively constant. The explanation of these facts will be apparent when it is remembered that the conductivity of the tissues is due to the presence of ions. The skin is poor in ions, their number varying considerably, according to the condition of the skin ; the underlying tissues and organs contain abundance of ions, and their proportion is relatively constant.

The outermost layer of the skin is the horny layer, and if it is quite dry, and if the electrodes in contact with it are dry metal, there will be no ions to conduct the current through the skin. If this current is the constant current and at a voltage not higher than that at which it is usually applied for medical purposes (say 50-70 volts), it will be unable to overcome the resistance of the skin and no current will flow. If, however, the sweat glands secrete, the dry skin will be moistened and contain ions, and some current will flow. If the skin is moistened with salt solution, as is customary before applying the electrodes, its resistance is artificially reduced, by reason of the diffusion into the horny layer of water containing ions.

The resistance and the body will vary also according

to the size of the electrodes ; if the latter covers a large area of skin there will be a large area of entry for the current and the resistance will be lower. The distance between the electrodes will also influence the resistance ; the longer the path for the current, the greater the resistance, and vice versa.

It will be seen, then, that the resistance of the body depends upon a number of factors and can vary within wide limits. If the constant current is used and is sent from one hand to the other, along the upper extremities and across the trunk, the hands being immersed in salt solution, the resistance may be taken as about 1300 ohms. When the resistance of the skin is excluded, the residual resistance is much less. Some experiments by Weiss showed that the resistance from shoulder to shoulder was 40 ohms, and from elbow to elbow was 250 ohms, when the skin resistance was excluded.

If the current is allowed to flow for some time and the metals of the electrodes be separated from the skin by pads soaked in salt solution, ions will actually migrate into the skin, and the resistance of the latter will progressively diminish, till it reaches its lowest value at the stage when it is permeated with ions. The phenomenon will be frequently observed during the process of medical ionisation ; the needle of the milliampere-meter will be seen to move gradually across the scale, showing that the strength of the current is increasing owing to the diminution of the skin resistance. If, however, the moistened pads contain ions that will form insoluble compounds when they come in contact with ions in the skin, the reverse will take place ; the needle will move in the opposite direction, showing a fall in the current strength. The resistance of the skin has increased because the number of ions in it has diminished.

The thick skin of the palms and soles has a higher resistance than the thinner skin elsewhere. Patients

who have been long confined to bed have a high skin resistance, because the horny layer is less readily shed and therefore thicker.

The body offers less resistance to currents that are alternating or intermittent, flowing for very brief periods in any one direction before interruption or reversal. Thus the resistance of the body is much less for faradic currents, and currents that alternate with a high frequency. The writer has measured the resistance of some hundreds of patients to the faradic current, previous to taking electrocardiographic records, and has found it to vary, in different individuals, from 500 to 700 ohms. The resistance was taken from elbow to elbow, the forearms being immersed in salt solution. The faradic and alternating currents do not alter the resistance of the skin like the constant current, because they do not cause a migration of ions into it.

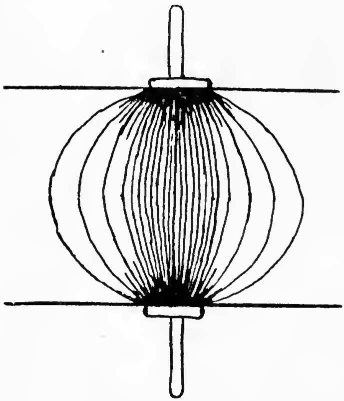


Fig. 29.—Diagram to indicate divergent lines of flow of constant current through tissues, with greatest density of current immediately under electrodes.

Path of the Current in the Body.—When the current has passed through the skin it encounters much less resistance in the underlying tissues. The path of least resistance will be the shortest path between the electrodes, and more of the current will pass that way, but some will take more circuitous paths, because, having a choice of several paths, it will distribute itself between them, the amount going by each one being inversely proportional

to its resistance. Some of these paths will loop out to each side (Fig. 29) beyond the parts enclosed between the electrodes, and the amount of current flowing along these paths will be less as the loops become wider and the paths between the electrodes become longer. It will be evident then that the deeper a tissue lies the smaller will be the share that it will receive of the whole current passing between the electrodes. The *density* of the current (that is, the amount of the current traversing a unit of sectional area at right angles to its path) will be greatest at the points of its entry and exit, and least at a point half-way between.

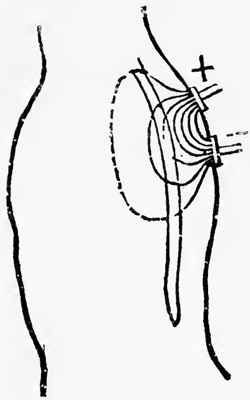


Fig. 30

If we imagine the current of electricity to be made up of thin lines or strands, where the density is greatest they are gathered together as in a cord. If the cord is frayed out the density is less, but the same number of lines are there. In its passage from one electrode to the other no lines are lost, but some of them will take a very circuitous route before being finally gathered in at the other electrode. If one electrode is larger than the other the density will be greater at the smaller. A certain minimum density of current is necessary to produce appreciable physiological or therapeutical results, and one may safely say that with the currents used in medical electricity the density in the outlying regions away from the direct line between the electrodes is so slight as to be of no importance.

If the electrodes are placed both on the same side of the trunk or a limb, the lines of flow of the current will

dip down into the deeper parts (Fig. 30), but the density of the current will be greatest under the electrodes and in the superficial parts, but very slight in the deeper parts. Very little current will travel *in* the skin itself between the electrodes on account of its high resistance. If the electrodes are placed on the same side, but farther apart, more of the current will flow through the deeper parts than if they are placed closer together (Fig. 31).

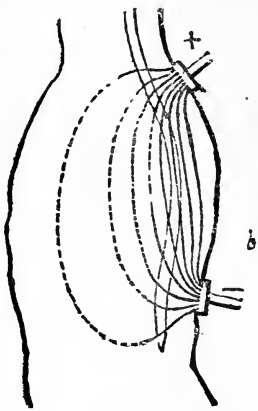


FIG. 31

It is important to remember the divergent path taken by the current between the electrodes. It explains why it is that a stronger current is required to stimulate a deep-lying muscle or nerve. Tissues that lie beneath the surface receive only a portion of the whole current, and a portion that becomes progressively smaller the deeper they lie. The divergent path taken by the current is one of the reasons why ions cannot be taken, from without, into the deep-lying organs in sufficient number to be of therapeutic value.

The milliampere-meter gives information of the total amount of current passing through the body, but not the amount passing through any one part of it.

The divergent path that has been described is that taken by the constant current. It is probable that currents which oscillate with a high frequency do not take such a path, but confine their course to the part lying between the electrodes, without spreading to those lying on each side.

Anode and Kathode.—The anode is the electrode by

which the current passes *into* the body (it may be remembered as the "in-ode"); the kathode is the electrode by which the current passes *out of* the body. In physiological experiments, in which we use excised muscle and nerve and place the electrodes in actual contact with them, the current is confined to them and there is one anode and one kathode, each localised to the point of contact of electrode with tissue. In the case of the body the conditions are quite different, and it is impossible to place the electrode or electrodes in actual contact with the muscle or nerve which is to be stimulated,

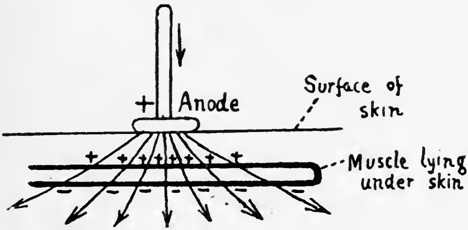


FIG. 32

but only at a distance from them with the skin and fasciæ intervening. Further, the muscle and nerve are not isolated, but in contact with tissues on all sides. These tissues all conduct the current, and it is therefore impossible to localise the current to the muscle or nerve or to localise anode or kathode to the region immediately under the electrode. There will be, instead, a number of anodes and kathodes scattered over the surface of the muscle or nerve. Fig. 32 shows, diagramatically, an anode overlying, but not in contact with, a muscle that is below the skin. It will be seen that on the side of the muscle facing the electrode there are a number of anodes, and a number of kathodes on the side away from the electrode. The current density will be greater on the side facing the electrode, so that when the latter

is, say, the anode, we are stimulating the muscle not with an entering current only, but with a leaving current as well, the former, however, being at a greater density than the latter.

Conduction of Currents at High Voltage.—The voltage at which the constant current can be applied to the body for medical purposes is not high and the current is dependent on the tissue ions for its conveyance through the body. If, however, the voltage is very high, as is the case with static electricity, the tissues are able to conduct the current like solid conductors, from atom to atom as well as through the agency of the ions.

CHAPTER V

IONIC MEDICATION

Definition.—It has been shown in Chapter I. that the results that follow the application of the constant (galvanic) current are to be attributed to the behaviour of the ions as they conduct the electricity. Ionic medication would, therefore, in its widest sense, include many of the branches of medical electricity, but the term is generally used for that form of treatment in which an electrical current is used for the purpose of introducing the ions of soluble medicinal substances into the body. The term "cataphoresis" is occasionally used instead of "ionic medication," but it should be reserved for another physical phenomenon that occurs during the passage of the current through the tissues—viz. the gradual passage of water from the region of the anode to the region of the kathode. Cataphoresis plays no essential part, so far as is known, in the process of ionic medication.

The meaning of the term "ion," and the way in which the ions can be made to move by the electrical current has been considered in Chapter I., and the process there described is that which is now generally believed to be that which takes place. Under the heading of Ionic Medication are grouped (1) the introduction of new ions from without, (2) the production of caustic bodies from the ions present within the body, (3) the alteration in the distribution of the ions already present within the body. The first of these will be now described.

The Use of the Electrical Current for Introduction of

Ions into Body.—There is enough experimental evidence to prove that ions can be carried into the body by the electrical current. The lithium ion and the iodine ion have been made to pass through the skin and have been detected in the urine and saliva. The strychnine ion can be made to pass through the skin of an animal and cause convulsions, and the cyanide ion ($\bar{CN}$) can be similarly introduced and cause rapid death. The entry of these poisonous substances is not by diffusion, because control animals with pads soaked in solutions of strychnine hydrochloride or potassium cyanide in contact with the skin are not affected if the current does not flow, nor are they affected if the current flows and the pads are connected to the wrong pole of the source of current. Cocaine ions may be made to pass into the skin and cause local anæsthesia. Here again the anæsthesia is not developed so long as the current does not flow.

Another good illustration of the power of the current to cause the ions to penetrate is seen when an ulcer is treated by zinc ions. The application of a dilute solution of zinc sulphate to the granulations at the base and edges produces no result that is visible to the eye. But if the solution is connected to the positive pole of a source of constant current, and the latter allowed to pass for ten minutes, the granulation tissue acquires a pearly white colour not only on the surface but in the deeper parts. This white colour is due to the formation of a compound of albumen and zinc. The zinc ions have entered, and many have entered into combination with the proteins.

Advantages of the Ionic Method.—The method of introduction of drugs, or, more correctly speaking, their ions, by the electrical current has special advantages which are possessed by no other method. The current passes into every part of the tissue that is to be treated,

and the ions travel along the same paths. Suppose, for example, an infected ulcer is to receive treatment by an antiseptic, such as zinc sulphate. If a solution of this salt is placed in contact with the ulcer, it will exert its germicidal action only on the surface, because it can penetrate only by diffusion, which process is very slow. If, however, the solution is connected to the positive pole of a battery, the zinc ions are now carried into the tissue. Every part with which the solution makes contact will be penetrated by the electrical current, so that all the cells and their intercellular spaces will receive the zinc ions. There is the further advantage that by using the electrical current, only the therapeutically active ion is taken in. In the case of zinc sulphate and the infected ulcers, the zinc ion, only, is taken in, and the SO_4 ion passes in the opposite direction. The refusal of some chronic ulcers to heal when germicidal solutions are placed in contact with them in compresses, and their prompt response and progressive healing after the introduction of the ions by the electric current, is frequently noticed by those who have experience of the ionic method of treatment.

Another advantage of the method is that the ions are introduced only into the region where they are wanted. If a drug is taken by mouth it is absorbed into the blood and is distributed to all parts of the body, and here again when it passes through the capillary walls it has to diffuse into the cells. By the ionic method it is taken in by the current.

Limitations of the Method.—The use of the electric current for the introduction of ions has this limitation—only the more superficial tissues receive them in numbers sufficient for therapeutic action. The deeper the part that requires treatment, the smaller the number of ions it receives. The reasons for this are the following.

In the first place, the current, in its passage through the skin and into the tissues, does not confine itself to the shortest path between the points of its entry and exit, but takes divergent paths into the deeper parts. The ions take similar divergent paths and so spread farther apart as they penetrate the deeper tissues. In the second place, the deeper the penetration the greater the number of blood vessels and lymphatics that may be encountered, and if any ions pass into the circulating fluid they will be carried away. Lastly, if the ions of the heavy metal are being introduced, they may come in contact with others in the tissues, with which they may unite and form insoluble compounds, and so are thrown out of solution.

When ions are introduced for the treatment of, say, a large joint, it cannot be expected that many, if any, will reach the deepest parts, and such beneficial results as are obtained are due, in part, to some ionic change and redistribution taking place in these regions, as well as to the action of the ions introduced into the superfic parts of the joint.

Depths of Penetration of Ions.—The depth to which an ion will penetrate depends, first, on the duration of the flow of the current; the longer the period of flow the greater the depth of penetration. Secondly, on the electro-motive force at which the current is supplied—a greater electro-motive force will drive the same ion farther, in the same time, than a lesser electro-motive force. Thirdly, on the ion; those composed of elements of low atomic weight will penetrate further than those of which the component elements have a high atomic weight, the time of current flow and the electro-motive force being the same for each ion.

Physical experiments have been carried out to determine the actual depth of penetration of ions into

non-living material. An electrical current was made to traverse a jelly containing sodium and chlorine ions to make it a conductor, and take in with it hydrogen ions from a solution of hydrochloric acid. The depths to which the hydrogen ions migrated was indicated by the decolorisation of the phenol-phthalein with which the jelly was tinted. The hydrogen ion was found to have travelled 10·8 mm. in one hour, with an expenditure of 1 volt of E.M.F. along each centimetre. Sodium travelled 1·26 mm. in the same time, potassium 2·05 mm. and chlorine 2·16 mm. With an expenditure of 10 volts along each centimetre the distances are ten times as great.

In the case of the tissues the conditions are different, and, such as they are, diminish the depth of penetration. The lines of flow of the current diverge and the ions therefore pass laterally as well as directly forward; other ions enter the blood and lymph streams and are carried away; others combine with tissue ions and may form insoluble compounds and therefore pass no further. The depth, therefore, to which ions penetrate into the tissues is not the same as for inert, simple substances, like the jelly in the experiment described above, and is probably less, and cannot be calculated from the factors given above. An experiment by Gautier showed that a current of 20 milliamperes was able, in ten minutes, to take copper ions into and through the wall of the uterus of a rabbit. Finzi introduced ferrocyanide ions through the skin over the knee joint of a monkey, and using a current of 10 milliamperes for thirty minutes was able to detect the ions in the cartilage of the joint.

Apparatus required for Ionic Medication.—For the practice of ionic medication we require: (1) A source of electric current. (2) Cords to conduct the current to the body. (3) Electrodes to lead the current from the cords into the body and, at the same time, hold the solutions

of the drugs the ions of which are to be introduced. (4) Solutions of the drugs.

(1) **The Source of Current.**—The current must, of course, be a *constant* current. It should be possible to regulate its strength between zero and a maximum, which, when the body is in circuit, and the conditions are those under which ionic medication is carried out, should reach a value of 100 milliamperes at least. To send such a current through the body an E.M.F. of at least 50 volts is necessary, though for a smaller current a lower voltage will do.

The constant current is sometimes called the *continuous* or *galvanic* current, and when obtained from the main is known as the *direct* current, or, for short, DC.

If the current from the main is available, and if it is a *direct* current, this will be the most useful and economical. Although this current, as supplied for domestic purposes, is much too strong for medical purposes, it can be suitably reduced, and the method of doing so is described on page 37. There is no risk of shocks to the patient or operator if the precautions detailed on page 54 are taken.

If there is no main supply, much can be done with a portable battery of dry cells. These batteries are described on page 60. When there is private plant for generating electricity, the current required may be taken direct from the dynamo. Or the dynamo may be used to charge accumulators. The current may then be taken from the latter when required. In this way the dynamo need be worked only on occasions when convenient.

If accumulators are used, a number of them must be connected in series, so that the voltage of the current may be sufficiently high to overcome the resistance of the body.

(2) **The Cords** that conduct the current to the body should be made of flexible stranded copper wire covered by insulating material. It is essential that the latter should be waterproof, because it is certain that they will be accidentally wetted sooner or later, and then the copper will gradually corrode and break. Further, the wire is no longer insulated where it is wetted, and if it should touch the patient's skin the current will pass out and form an additional circuit and perhaps cause blisters at the point of contact. A flexible stranded copper wire with its ends securely soldered into firm metal end-pieces of larger diameter may be enclosed within a narrow rubber tube ; the free ends of the latter are stretched over the end-piece, making a waterproof covering of the soldered joint, but leaving the end free, so that it can be fixed to the binding screw of electrode or battery. Cords of this kind have been used during the past few years in the electric department at St Bartholomew's and have proved to be very satisfactory.

(3) **The Electrodes.**—The electrodes consist of two parts: (*a*) an absorbent pad, which is soaked in the solution containing the ions ; (*b*) a metal plate of rather smaller area than the pad and bearing a binding screw for attachment of the cord.

The pad that contains the solution should be made of absorbent material, such as lint, glass cloth, towel or Gamgee tissue. It should be of a thickness corresponding to sixteen layers of lint. Separate strips or layers can be placed one over the other, or a large sheet may be folded and refolded till it has the desired thickness.

The metal plate, to which is attached the cable, may be made of sheet brass. Aluminium may be used, but is more likely to break after much bending. The metal plate may be placed direct on the pad, but if a layer of felt is placed between, the layers of lint may be reduced

to eight. The felt should be a quarter of an inch thick, and it should be of larger area than the metal, so as to overlap it half-an-inch all round. The felt should be stitched to the metal, and, for this purpose, the edges of the plate should be perforated for the passage of needle and thread. These perforations should be one-eighth of an inch wide and placed in pairs, at the corner, and, if necessary, at the sides. The felt has to be taken off frequently for cleaning, and it takes less time to stitch it on if the metal plates are perforated as described than if small holes are drilled all the way round the edge.

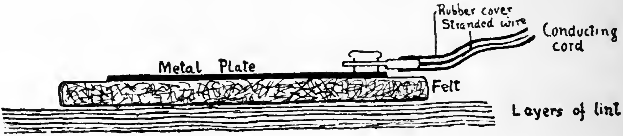


FIG. 33.—Diagram of Electrode

These felt-covered metal plates are useful for other electro-medical purposes as well.

An electrode is shown in section in Fig. 33.

The absorbent pad should be of sufficient size to cover the part that is to be treated. The felt should be of smaller size than the pad, while the metal plate should be smaller than the felt.

When the electrode is in position the pad is in contact with the skin, and the felt, with the metal, rests on the pad. It will be seen that with this arrangement the metal is situated some distance off the skin. The importance of this will be evident when it is recollected that, as described in Chapter I., new ions possessing caustic properties are formed at the points where the solid and the fluid conductors are in contact. At the metal plate of the electrode that forms the *kathode*, $\overset{+}{Na}$ and $\overset{-}{OH}$ ions are formed. The latter are repelled from the kathode

towards the skin. If the pad and felt are thin, they will finally reach the skin, and, being caustic, will, if in sufficient concentration, cause burns. In the case of the anode, ions of the metal forming the plate lying on the absorbent pad, will migrate towards the skin. If the pad is thin they will soon reach it. In some cases it is intended that the ions of a metal shall be introduced, but not necessarily those of the metal forming the electrode (copper and zinc when the electrode is made of brass). In other cases, positively charged ions other than those of metals (quinine ions, for example) are to be introduced, and in these cases the ions of the metal forming the electrode are not desired. A pad like that described is sufficiently thick to hold sufficient solution and an ample supply of the ions to be introduced. At the same time the ions of the metal part of the electrode will not have time to reach the skin as the pad is sufficiently thick.

(4) **The Solutions** need not be more than 1% in strength. It must not be thought that more ions will be introduced if the solution is stronger. The stronger the solution the larger the proportion of undissociated molecules. Stock solutions of 10% strength may be made and diluted with ten times the bulk of water when required for use. Tap-water may be used if it is not "hard." If it is hard, and contains much carbonate or bicarbonate, precipitates will be formed if it is used to dilute zinc salts. To allow for this, the zinc salt may be diluted rather less, or distilled water may be used. The ions present in the tap-water will be introduced at the same time, but there is no evidence that they produce any appreciable effect.

In some cases the substance to be introduced need not be already in the ionic state before the current is passed. For example, if the zinc ion is to be introduced, we may

use the metal itself instead of a solution of one of its salts, and connect it to the positive pole. When the current passes, the metal slowly passes into solution, so that its ions are formed. Those ions then migrate into the tissues. It is more convenient to use the metal when parts difficult to reach with the solution—*e.g.* sinuses—have to be treated by the ionic method.

The Ions used in Medicine.—These may be arranged in two tables, according to the charge which they bear. Against each ion is placed the salt from which it may be most conveniently obtained, and the strength of the stock solution.

Ions with – Charge (known sometimes as "Anions")

Chlorine ($\bar{Cl}$). From solution of common salt. (The salt is best stocked in the solid condition, and a solution of three teaspoonfuls to a pint of water made when required.)

Iodine ($\bar{I}$). From solution of potassium iodide or lithium iodide (10%).

Salicylic ions. From solution of sodium salicylate (10%).

Ions with + Charge (known sometimes as "Kations")

Zinc ($\overset{+}{Zn}$). From a solution of zinc sulphate (10%).

Magnesium ($\overset{+}{Mg}$). From a solution of magnesium sulphate (10%).

Lithium ($\overset{+}{Li}$). From a solution of lithium chloride (10%), or lithium carbonate. (The latter is only slightly soluble.)

Silver ($\overset{+}{Ag}$). From a solution of silver nitrate (10%). (Distilled water should be used.)

Copper ($\overset{+}{Cu}$). From a solution of copper sulphate (10%).

Mercury ($\overset{+}{Hg}$). From a solution of mercuric chloride (10%).

Quinine. From a solution of quinine hydrochloride (10%).

Cocaine. From a solution of cocaine hydrochloride (10%).

Adrenalin. From a solution of adrenalin chloride (1 in 1000).

Practical Application.—If the part to be treated lies under the skin, the latter should be first freed from greasy secretion by washing with soap and water and then thoroughly rinsed. Or the skin may be wiped with ether or acetone. Any skin lesion should be covered by a scrap of waterproof material, such as thin sheet rubber or adhesive plaster. The pad, soaked in the solution, diluted to a 1% strength and sufficiently wrung out, so that it does not drip, is placed on the grease-free skin, so as to make good and even contact all over. It is very important that there should be good contact all over. The metal with the attached felt is soaked in the same solution and placed on the pad, bent, if necessary, so as to make good apposition. The two are then securely fixed, by means of a bandage. The connecting cord from the battery is then attached to the metal plate binding screw. This is known as the "active" electrode.

In order to complete the circuit, another electrode is required. It is exactly the same as the active electrode, and it is soaked in salt solution. It is placed on some convenient part of the body, away from the active electrode. In area it should be equal to or larger than

the active electrode, never smaller. It is known as the "indifferent" electrode.

If more than one part is to be treated, we may use *two* "active" electrodes, and place one over each part. A different ion will, of course, be taken in from each electrode, one electrode being positive, the other negative. The two active electrodes should be of the same area. Or, two or more active electrodes may be used, and one indifferent electrode. In this case two or more conducting cords will be required, one to each active electrode. The area of the indifferent electrode should be equal to or larger than the united area of the active electrodes.

The pole of the battery or other source of current to which the active electrode or electrodes should be attached depends upon the electrical charge of the ion that is to be driven in. Pads containing ions with the positive charge (kations) are connected with the positive pole of the source of current. Ions with the negative charge (anions) are placed in the pads connected to the negative pole.

When the circuit is completed the current is started. It must always be started from zero, slowly and gradually increased till the maximum is reached, at which it may stay for the period of the treatment. It is then gradually diminished till it reaches zero. The *sudden* switching on of the current or the *sudden* switching off will cause the patient to feel a smart shock, and must be avoided. The too rapid increase in strength of the current, or the too rapid diminution, will cause pain without shock.

When the current has reached a small value the patient feels a pricking, tingling sensation. It soon disappears, and as the current is further increased he begins to perceive a hot, burning sensation over the whole pad. This again diminishes, but when the current is increased beyond a certain value the sensation persists, and the

current should not be further increased. The maximum value should not be more than 2-3 milliamperes per cubic centimetre (*i.e.* 12-18 per square inch). If the patient persistently complains of burning pain localised to one spot, it may mean that excessive current is being concentrated there (owing to uneven contact of pad and skin, or uneven soaking of the pad), and the current should be slowly decreased to zero and the pad and skin examined.

It will be noticed that when some ions are being driven in, the current, as indicated by the milliampere-meter needle, will show a spontaneous increase in its strength. This is because the saturation of the skin with ions reduces the resistance of the latter to the lowest value. On the other hand, other ions, like those of the heavy metals, form insoluble compounds with the tissue ions, so that the current-conducting ions are diminished in number and therefore the milliampere-meter needle moves back towards zero.

If the ions have to be introduced into a tissue from which the epithelium or superficial fascia has been lost, such as a wound or ulcer, any scabs or crusts should be first removed and the surface then swabbed with water or saline to wash away discharge. The pad should then be evenly applied to the cleaned surface. If the surface is very irregular, the uniform contact without leaving any part untouched may be secured by withdrawing, with a dissecting forceps, small portions of cotton wool from a roll, dipping them in the solution and placing them in the crevices and irregularities till they are filled and a smooth surface obtained, to which the lint pad may then be applied.

Ionisation of Sinuses.—The ionisation of sinuses is more difficult, because it is less easy to ensure contact between the electrode and every part of the wall. If the

ions of zinc, copper or other metals are to be introduced, a rod of the metal covered by lint soaked in a solution of a salt of the metal may be inserted into the sinus down to its end. If the sinus is narrow, the uncovered metal may be used. An alternative method is to pass a fine brass tube, filled with some antiseptic solution, such as zinc sulphate (1%), down the sinus to its end, attach a syringe filled with the same solution to the end of the tube and force the solution from the end of the tube, at the same time slowly withdrawing the latter, but not completely. The tube is then passed again to the end of the sinus and the process repeated. By this method there is more likelihood of the solution coming into better contact with the wall of the sinus, and less chance of any part escaping contact with it. A terminal is attached to the tube, so that the latter can be connected to the battery or source of current.

When connected to the positive pole, zinc ions migrate into the walls of the sinus. At the same time the metal of the tube gradually dissolves, forming ions, so that further ions (zinc and copper, from the brass) migrate into the wall.

If it is wished to try the disinfectant action of ions other than those of metals, the metal tube must be connected to the proper pole of the battery. Thus if the salicylic ion is used the tube is connected to the negative pole.

The Ionisation of Less Accessible Regions.—Different methods have to be adopted if ions have to be introduced into less accessible parts. If the walls of a cavity, such as the maxillary antrum, are to be ionised, the cavity is first filled with the solution containing the ions (after a preliminary wash out with water), by means of a metal tube or catheter. The metal tube also serves to conduct the current into the solution within the cavity. It must

be carefully insulated, except at the point where it is inserted into the cavity. Otherwise the current will pass into any other part with which the tube may happen to be in contact. The insulation may be brought about by sliding a rubber tube over the metal.

For ionising the wall of the rectum for ulceration and inflammation different methods are used. One method is to insert a zinc rod, six inches long, and covered by four layers of lint soaked in zinc sulphate solution (Wallace & Ironside Bruce). In another method a special electrode devised by Herschell may be employed. It consists of a copper or zinc wire bent to the form of a close spiral, enclosed in a rubber tube closed at one end, with a side opening near this end. The rubber tube with the enclosed spiral is contained in a larger membrane bag, which is wrapped closely round it. The whole is introduced into the rectum, with only the end projecting. Zinc sulphate solution can be made to flow, by gravity, slowly into the rubber tube from a douche can sufficiently elevated. It passes through the perforation and unwraps and distends the membrane bag into contact with the walls of the rectum. The metal spiral is connected to the positive pole of the source of current. Zinc ions migrate through the membrane into the rectal wall. A similar apparatus may be used for the vagina.

The mucous membrane of the colon may be ionised, in cases of colitis. Curtis Webb has described a method. An electrode made of a wire spiral, twelve inches long, enclosed in a rubber tube closed at the distal end and provided with a side opening near this end, is inserted as high up the colon as possible through the anus. Two indifferent electrodes are used; one is placed on the front of the abdomen, the other on the lumbar region. They are connected to the negative pole of the source of current. From a douche can a hot solution of zinc sulphate

(2%) is gradually run through the rubber tube containing the spiral. It slowly fills the rectum and colon. The current is switched on and gradually increased till it reaches 15-20 milliamperes. It is allowed to flow for ten to fifteen minutes and then gradually turned off. While the current flows, more of the solution should be allowed to flow in, so long as the patient tolerates it. The wire spiral is connected to the positive pole of the source of current.

In all cases where the interior of the bowel or other cavity is to be ionised, it is advisable to wash it out beforehand with warm water (distilled, if silver nitrate is to be used afterwards), so as to remove substances which might combine (like pus, for example) with the solution afterwards introduced ; the lavage further clears away any substance in contact with the wall of the cavity.

Duration of Ionic Treatment.—The duration of each session of treatment will vary according to the case, and definite times cannot be given. If a very slight thickness of tissue is to be ionised, as in the case of a corneal ulcer, the session need not last longer than a minute and a half or two minutes. If the part to be ionised lies some distance below the surface, such as the sciatic nerve, the session should last longer, even as long as an hour.

The interval between two successive sessions of treatment—when more than one is necessary—also depends upon the case. When ions like zinc, copper, etc., that have caustic properties are used for treatment of sores and raw surfaces, the treatment should not be repeated until a week or ten days have elapsed. When ions that have no caustic action are used and the part to be treated lies under the skin, the sessions may be more frequently held, even every other day. If the erythema and slight degree of tenderness that follows each session have subsided, the treatment may be repeated.

The foregoing is a brief account of the principles of ionic medication, and the way in which it may be carried out. In Chapter XIV., in which the most suitable electrical treatment for different diseases and morbid conditions is set forth, reference will be found to those for which ionisation is the method recommended.

CHAPTER VI

SURGICAL IONISATION—THE USE OF THE ELECTRICAL CURRENT FOR DESTRUCTION OF TISSUE

Principle of the Method.—It has already been shown that new ions make their appearance at the points where the current leaves the anode to enter the electrolyte, and where it leaves the electrolyte to reach the kathode. Hydrogen ions are formed at the anode (if the latter is made of platinum) and hydroxyl ions ($O\bar{H}$) at the kathode. In addition, there is some free undissociated hydrochloric acid at the anode and caustic soda at the kathode. These ions and molecules have a caustic action and, as they migrate away from the electrode at which they are formed, precautions have to be taken, as described in Chapter V., to prevent them reaching the skin. When, however, it is wished to make use of their caustic properties for the destruction of tissue, special arrangements can be made for the purpose. The details differ according to the tissue that is to be treated, but the principle of the method is as follows. The electrodes consist of metal only. They are made of very small size and take the form of needles, so that, in the first place, the current will be very concentrated where it enters and leaves the tissue, and the number of ions formed at these points will be sufficiently large to produce caustic effects. In the second place, the needles are inserted into the tissue, so that the caustic action can be localised in the situation desired. If the needles are made of platinum the ions liberated will be hydrogen at the anode, and hydroxyl at the kathode. If the needle forming the anode is made

of zinc or copper, then zinc ions or copper ions (not hydrogen ions) will be formed at the anode; being present in concentration around the needle, they will exert a caustic action.

In carrying out surgical ionisation we may use one active electrode and an indifferent electrode; the latter is of the same kind as that described in the last chapter (page 77). The active electrode may consist of a group of needles, instead of a single needle, and all are connected to the same pole of the source of current. The indifferent electrode can be replaced by a needle or group of needles which are connected to the opposite pole, so that all the electrodes are active.

The destruction of tissue by the ions liberated by the electric current is sometimes spoken of as electrolysis, and the action of the current as electrolytic The electrolytic action is really a chemical action of the ions liberated by the current. With regard to the method, its great advantage lies in the fact that only so much of the caustic as is wanted is produced, and the caustic is made in the area where its effects are desired. The action is thus exactly localised and under perfect control.

It has been employed for the removal of superfluous hairs, warts, moles, destruction of nævi, strictures and cancerous growths, in the treatment of fibro-myoma of uterus, and to produce coagulation in an aneurysmal sac.

The cases for which surgical ionisation is a suitable method of treatment will now be mentioned together with the method that may be adopted for each.

Removal of Superfluous Hairs.—For this purpose the caustic ions and molecules forming round the kathode are used to destroy the hair follicle. To do this successfully a good light is necessary. The indifferent electrode —the anode—is placed on any convenient part of the patient's body. The other pole is connected to a needle-

holder to which is attached a fine platinum needle. The needle should be not thicker than 0·2 millimetres (Fig. 34).

The current is best derived from dry cells. With a battery box like that described on page 61, the current collector can be turned so as to take four cells into the circuit. The circuit should be completed, so that the current flows when the needle reaches the follicle.

The operator steadying the hair with the forceps introduces the needle into the follicle passing in the proper direction alongside the hair. The needle enters from one-sixth to one-eighth of an inch. In about five seconds or so a slight effervescence is seen at the orifice of the follicle, and the needle is withdrawn. The hair

FIG. 34.—Epilation Needle fixed to Holder

should come out by very gentle traction. If not, the needle may be inserted again for a couple of seconds. The point of the needle must not be too sharp. A dull point finds its way down into the follicle more easily. Platinum needles should always be employed and sterilised in the flame of a spirit lamp before use. There is a sharp stinging pain at the moment the needle is in the follicle, but it is not so severe that an anæsthetic is necessary. The local application of cocaine is useless unless introduced by the ionic method; even then it is not advisable.

When a large number are to be removed, only from twenty to thirty should be done at a single sitting, and these should be removed from over the whole surface. If this number were removed from one spot a troublesome ulcer might result and leave a scar. The successful use of this method requires both practice and skill. Under the best conditions a certain number of the hairs return and have to be removed again.

If the terminal quarter inch of the needle is bent nearly to a right angle with the long axis of the holder, the view of the mouth of the follicle is less obscured by the holder and the needle is more easily inserted. The latter must be sufficiently stiff: for this it should be made of iridium rather stouter than 0·2 mm., with the terminal quarter inch 0·2 mm. in diameter.

Nævi.—Ionisation is a most valuable method of treating nævi, and in many cases the only satisfactory one. With practice the operation is under perfect control and the results in suitable cases are all that can be desired. The object is to break up the blood vessels and coagulate the blood therein without causing general necrosis and sloughing. The destruction of the vessels and coagulation of the blood is caused by the caustic ions formed around the electrodes.

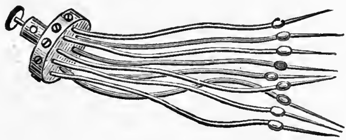


FIG. 35.—Needles for Electrolysis

If the growth is subcutaneous, the skin is not to be interfered with in any way except for the minute openings where the needles are inserted. If the skin is also involved, a certain amount of scarring is unavoidable.

There are two chief methods of carrying out the destruction of nævi by the ionic method—the unipolar and the bipolar methods.

The Monopolar Method.—A large indifferent electrode is placed on any convenient part of the body and connected to the positive pole. The needle or needles are attached to the negative pole of the source of current and introduced into the nævus.

Fig. 35 shows a holder with nine needles, one or more of which may be inserted as required.

In a large nævus they should be introduced evenly

through the mass, and the indifferent electrode must be very large and accurately applied. Where individual vessels can be recognised, the needle should be made to pass near, or even transfix them. When the nævus is situated on the face or head, the current, in its passage through head and neck to reach the indifferent electrode, may cause shock and faintness and irregular breathing, especially in children. In the bipolar method the current is confined to the nævus and does not traverse the central nervous system.

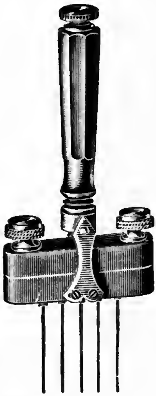


FIG. 36

In all cases the current is to be turned on and off very gradually. The currents used are large and if the needles are suddenly removed without first lowering the current to zero a severe shock would result. The current should not exceed 20 milliamperes per inch of needle inserted.

The Bipolar Method.—This is to be preferred in most cases and is best carried out by means of a bipolar needle-holder devised by Dr Lewis Jones and shown in Fig. 36.

The two wires from a battery are joined to the two terminals shown. The internal connections are such that the needles are joined to the positive and negative poles alternately. Two, three, four, or five needles may be used, according to the size of the mass to be treated. From four to six cells are turned on and then the needles are pushed through the mass. A milliampere-meter must be in circuit and the current not allowed to exceed 20 milliamperes for each inch of positive needle inserted. Here again the needles should be of platinum and sterilised by heating to redness before use. The needles should be inserted parallel with the surface. They

should then be partially withdrawn and pushed in again in a different direction. The process should be repeated several times, so that the needles explore all parts of the nævus and break up its blood vessels. While this is being done watch is kept on the skin where the needles have pierced it, so as to avoid the risk of destroying it. Soon after the needles are inserted the tissues round them begin to change colour. Round the positive needles there is hardening and pallor and the needle tends to become fixed and difficult to withdraw. Round the negative needles there is frothing with hydrogen gas given off, while the needle itself gets very loose. The tissues tend to become dark and livid round the negative needles and on the first sign of this should be withdrawn and reinserted in a fresh place if the nævus has not already acquired the firm consistency indicating complete coagulation. In using this holder, Dr Lewis Jones considered the current should not exceed 20 milliamperes per inch of *positive needle,* if sloughing is to be avoided.

The application of the needle should continue till the nævus acquires a firm consistency.

Other variations of the above-described methods and appliances are advised and used, but these given will be found quite satisfactory in nearly all cases. The pain is severe, and an anæsthetic is required in practically every case. For after-treatment a piece of antiseptic gauze is applied over the punctures with flexible collodion. If sloughing supervenes an antiseptic poultice is applied at first until the slough is cast off and the ulcer treated on general principles. Small nævi, not over one quarter of an inch in diameter, can be destroyed at a single sitting. When larger than this, two or more sittings may be necessary.

The aim should be to destroy the nævus, either completely or as far as possible, at the first sitting. As the

tendency of most nævi is to increase in size they should be treated at the earliest possible time, and special attention should be given to the margin in all cases if recurrence is to be avoided.

It has been suggested that copper needles should be used in place of platinum, with the idea of depositing a salt of copper in the nævus. Good results are obtained, but the use of copper does not appear to have a special advantage over the metal usually employed.

In treating port wine marks, a single needle is used connected to the negative pole. The indifferent electrode is positive and placed on the sternum or other convenient part. The needle is inserted into the skin vertically and a current of 3 to 4 milliamperes passed for a short time. The area must be treated in a number of sittings—the needle at each sitting being introduced at various points scattered over the surface, as is done in removing superfluous hairs. The obliteration of extensive port wine marks take a very long time, as the area treated at each sitting is small.

Stellate Veins.—These are treated by passing a zinc needle, attached to a suitable holder for a short distance, say about one-eighth of an inch, into the central vein from which the others radiate. The needle is connected to the positive pole and the circuit is completed by placing the indifferent electrode on some other part of the body. A current of 1 milliampere is passed for one minute. The central vein is coagulated by the zinc ions and the radiating vessels disappear. A minute scab forms, but drops off in a few days, and leaves a minute scar, which afterwards becomes almost invisible.

Warts.—These are treated in the way described for stellate veins. The zinc needle is made to transfix the base of the wart at the level of the skin. A current of

1 milliampere for one minute is sufficient. If the wart is larger than about one-eighth inch in diameter it may be transfixed again, once or more, in different directions, and the same strength of current applied and for the same time.

This treatment is very successful. The wart gradually shrivels and drops off in a week or ten days.

The method described is sometimes called "zinc needling."

Moles.—Hairy moles are best treated by removing the hairs in the way previously described. Much of the pigment will disappear when the hairs are removed. Moles that are not hairy can be removed in the way described for warts.

Strictures of Urethra.—Very little has been heard of the electrolytic treatment of strictures during recent years. It offers no very decided advantages, and if sufficiently strong currents are used to produce active destruction of the scar tissue at the stricture, it is attended with some danger. A large indifferent electrode is placed on any convenient part of the patient's body, and is connected to the positive pole. The active electrode consists of a catheter-shaped bougie, terminating in a bulbous enlargement. The latter is left bare, and the stem is covered with insulating material—the whole being more or less flexible. One is shown in Fig. 37.

At the outer end is provided a terminal for attaching it to the negative pole. The size of the largest bougie that will pass the stricture as well as the distance of the latter from the meatus, having been ascertained, a bougie electrode is selected two sizes larger, and a mark made on its shank corresponding to the distance of the stricture from the meatus. It is now passed down to the stricture against which it is held, but no force is to be used under

Fig. 37

any circumstances. The circuit is closed and the current gradually turned on until 5 or 6 milliamperes are passing. The pressure on the bougie must be gentle, and in the direction of the urethra, otherwise a false passage may be made. The pressure is kept up until the bougie passes through the obstruction and into the bladder, when the current is to be at once gradually reduced to zero and the instrument removed.

This operation may have to be repeated at intervals of not less than three weeks.

Another method is that of "linear electrolysis." The active electrode consists of a long, flexible bougie, in the middle of which is a projecting blade of platinum (not sharp). This blade is connected to a terminal at the outer end. The leading end is filiform and serves as a guide. The instrument is introduced, and the blade pressed against the stricture. The current is gradually turned on until 10 milliamperes is reached, which is sufficient in most cases.

The method is one which might be termed "electrolytic incision." The instrument is pressed against the stricture until the latter is divided, which takes place in about thirty seconds. Strictures in other parts, such as the lachrymal duct, eustachian tube, œsophagus, and rectum, have been treated by electrolysis with more or less success. The method differs in no essential particular from those given for stricture of the urethra.

Uterine Fibromyomata.—A great deal has been written for and against this treatment of uterine "fibroids" since Apostoli published his method in 1882.

The action is to destroy the uterine mucous membrane, which results in a reduction of the size of the uterus and a decrease of the hæmorrhage. The most that can be gained in the great majority of cases is of a palliative character.

Apostoli used an internal positive electrode of platinum, and an indifferent electrode of moist china clay, and a current of from 50 to 80 milliamperes passed for from five to fifteen minutes. The method is not much employed now.

Aneurysm.—The treatment of this condition by electrolysis has not been satisfactory. The best results in this country have been obtained by the late Dr John Duncan, of Edinburgh. It is only applicable in cases where ligature is impossible or attended by special risks. The great objection to the method is the necessity of piercing the wall of the sac with the risk of setting up hæmorrhage. The needles must be insulated except at the points, so that no bare metal comes in contact with the sac during the passage of the current. Both positive and negative needles are introduced into the tumour, and large currents and long sittings are the rule.

Malignant Growths.—In the hands of some workers good results have been obtained in the treatment of carcinoma and sarcoma. The method which appears to have been most successful consists in plunging into the cancerous mass one or more small rods of amalgamated zinc—a puncture being first made with a scalpel to permit of the insertion of the rod or rods. These are connected to the positive pole of the battery—a large indifferent electrode being arranged under the patient. A general anæsthetic is always necessary. Large currents and long sittings are the rule, and the whole proceeding is more or less elaborate application of the ions of zinc and mercury. Complete destruction of the growth takes place in the immediate vicinity of the anodes and atrophy in the area farther away. It is largely practised by Dr Betton Massey, of New York, who claims that he has had very good and encouraging

results in a large number of cases of inoperable malignant disease. The method has not been used to any great extent in this country, but it ought to be given a further trial. It does not prevent the occurrence of metastases.

CHAPTER VII

IONISATION IN DEEP-LYING TISSUES

In the methods of treatment described in the two preceding chapters the constant current has been used for definite purposes: first, to take into the diseased part the ions of the drugs of which the therapeutic action is known; secondly, to deposit the ions of caustic chemicals where desired, in order to destroy tissue.

The constant current is known also to produce therapeutic effects in general or local maladies in which its *modus operandi* is less evident. The effects are not due to the ions that are taken in from without, because these ions may have no therapeutic value. Thus the electrodes may be soaked in salt solution: under these circumstances sodium ions enter at the positive electrode and chlorine ions at the negative electrode. It is unlikely that the good results that follow the application of the constant current to a sprained joint, for example, are due to the entry of sodium ions from the positive electrode and chlorine ions from the negative electrode. Even if the ions of drugs known to be of value in the treatment of disease are contained in the electrodes, they are not likely to reach the deepest parts in the time during which the current is usually allowed to flow during a session of treatment. It is therefore necessary to seek some other explanation. The question must nevertheless be considered from the point of view of the behaviour of the ions. The constant current causes a steady movement of the ions *normally present within the tissues*, either in the same direction as the current or in the opposite

direction, according to the charge carried by the ion. There must therefore be some redistribution of the tissue ions. It cannot be said whether such redistribution has any therapeutic effect, but it is possible that there are ions of disease products in some morbid conditions, and if such is the case the constant current would cause their migration out of the tissue and into the vessels. A mode of action of this kind was suggested in Chapter I. to explain the disappearance of fatigue from tired muscles, following the application of the constant current.

The migration of the ions acts as a stimulus, at any rate to some of the tissues, as, for example, the sensory nerves. The steady flow of the current through the skin causes a burning sensation as the ions pass through the sensory nerves.

The erythema that is evident in the skin after the current has been passing through it shows that vasodilatation is produced. It is likely that there is some vasodilatation in the deeper parts also and possibly some stimulation of the tissues in the same region. In those maladies where the passage of the constant current produces cure or relief, the tissue stimulation and vasodilatation may be contributing factors. The passage of the current through a fluid effusion such as is found in a joint after injury is often followed by its disappearance. It is possible that this disappearance may be due to migration of ions from it and lowering of its osmotic pressure.

To apply the current for treatment of diseases of the deep parts, electrodes like those described in Chapter V. for medical ionisation may be used—viz. absorbent pads for placing in contact with the skin and felt-covered metal plates for attachment to the cords leading from the source of current. They must, of course, be soaked in a solution of an electrolyte, so that they may conduct

the current. Sodium chloride is used. If it is wished to introduce some special ion as well as to influence the deep parts, the pad is soaked in a solution containing the ion and connected to the correct pole. If sodium chloride is used, sodium ions will migrate inwards from the pad connected to the positive pole, chlorine ions from that connected to the negative pole. It is important that the electrodes should be of sufficient size so as to overlie the whole of the part requiring treatment. With small electrodes the maximum current density that the skin can tolerate is reached with a small current, and when this small current has spread along divergent paths in the deep parts the amount of current in any one part is very small. For application to the abdomen, an electrode that covers the whole of the anterior surface should be used, while another of the same size should be placed on the back. For application to the brain, one electrode (the kathode) is placed so as to cover the forehead, the other is placed on the back of the neck. For the spinal cord an electrode three inches wide and of a length equal to that of the part to be treated is placed over the vertebral column. This electrode is usually the kathode. The anode may be placed on the front of the chest, its total area of contact with the skin being not less than that of the kathode.

If the shoulder is to be treated, it should be surrounded as far as possible by strips of lint soaked in the electrolyte, and a piece of felt-covered metal, bent so as to fit over the deltoid, placed in contact with the lint and bandaged in position. The other electrode may take the form of strips of lint wound round the forearm, with a felt-covered metal plate measuring, say, six inches long by two inches wide in contact with the lint, over the anterior or posterior surface of the forearm. If may be more convenient to dispense with the lint and immerse the forearm in a solution of the electrolyte in the arm vessel of a Schnee

bath (page 113). The solution takes the place of the soaked lint pad, while a metal plate immersed in it, but not in contact with the skin, connects it to the source of the current. If desired, the pad around the shoulder may contain the ions of a drug, which will then enter the superficial part of the joint where the latter does not lie deeply. The pad must be connected, of course, to the correct pole of the source of current. If it is not wished to introduce ions from outside, an alternative method of applying the current to the shoulder is to fix electrodes one to each arm, or to immerse each forearm in a Schnee bath. The current then passes through both shoulder joints. For the hip similar arrangements may be made as for the shoulder. If an electrode is placed over the hip, it should be of large area and pass round from the gluteal region to the groin, which should be overlapped. The other electrode should be placed on the leg, or the leg may be immersed in a Schnee bath.

Another method of applying the current is to place one electrode over the front of the hip in the region of the groin and upper part of the front of the thigh, and the other electrode over the gluteal region. If both legs are immersed in the Schnee bath the current will traverse both hip joints and the intervening parts as well.

Among the morbid conditions for which the application of the constant current produces good results may be mentioned *congestion*, particularly when the exciting cause (*e.g.* trauma) has ceased to act. The results are not at all likely to be due to the introduction of ions from without. Some cases of progressive muscular atrophy are benefited by application of the constant current to the spine. The same treatment often relieves the crises and pains of tabes dorsalis, and it is of value in some cases of neurasthenia and hysteria. Leduc recommends its application to the brain in cases of cerebral fatigue and exhaustion.

The diseases for which the application of the constant current, "galvanisation" as it is often called, is suitable will be found in Chapter XIV. In these cases the current is not applied for the purpose of introducing new ions from without.

CHAPTER VIII

THE USE OF THE ELECTRICAL CURRENT FOR STIMULATION OF THE TISSUES; ELECTRIC BATHS

A VALUABLE property of the electric current when applied for the treatment of disease is its power to produce general stimulation of the tissues. Such stimulation is more effective if the current is rhythmically varied in strength and direction of flow. The experiments of Debedat on the stimulating action of different currents on the growth of muscle (see page 121) showed that a constant current produced only a slight increase in the size of the muscle, while a current that was interrupted, flowing for periods of one second, each period of flow being followed by a period of rest of equal length, caused an increase by 18%. In many diseases and morbid conditions the electric current produces good results by reason of its stimulating action on the tissues of the body. The *continuous* current causes a migration of ions wherever it flows; the current if interrupted or reversed or modified in various ways causes, not a steady onward movement or migration of the ions, but interrupted movement or to-and-fro movement, or movement modified in accordance with the modification of the current. This irregular movement of the ions is a stimulus to the tissues of the body. Muscles will contract, nerves will be stimulated, and other tissues will be stimulated to give their customary physiological response. The beneficial effects that follow the electrical treatment, by means of interrupted currents, of general maladies, such, for example, as

rickets or anæmia, or of the symptoms grouped under the heading of "general debility" are to be attributed to the general stimulation produced by the current, or, as it should be said, by the ionic movement produced by the current. This power to produce general stimulation of the tissues is one of the most valuable properties of electricity in the treatment of general and local diseases.

Modification of Current for Stimulation of Tissues.—In Chapter II. modifications of the constant current have been described, together with the ways in which they may be obtained from the constant current. These modifications may be tabulated and summarised as follows :—

1. **Simple Interrupted Current.**—This is obtained from a constant current (from main, or battery of cells) by including in the circuit either—

   (*a*) A metronome interrupter. The current interruptions are abrupt and infrequent;

   (*b*) A Leduc interrupter. The current interruptions are abrupt. The frequency of interruption can be varied and the duration of the periods of flow and no-flow can be varied and measured.

2. **Simple Alternating Current.**—This is obtained from a constant current (from main, or battery of cells) by including in the circuit a revolving Ruhmkorff commutator. The interruptions are abrupt, and short periods of rest occur between the reversals. The interruptions and reversals are frequent and can be varied.

3. **Sinusoidal Alternating Current.**—This may, in some districts, be supplied on the main. Otherwise it may be obtained from a constant current (from main, or battery of cells, or accumulators) by including in the circuit a motor transformer. The alternation is frequent ; there

is no period of rest between the reversals, and the rise of current strength from zero to maximum is not abrupt.

4. **Slow Sinusoidal Alternating Current.**—This is obtained from a constant current (from main, or battery of cells, or accumulators) by including in the circuit a slowly revolving motor transformer or Ewing's rhythmic reverser.

5. **Faradic Current.**—This is obtained from a constant current (from one or two dry cells, or, if desired, from the main, the current being suitably reduced) by including in the circuit an induction coil. The current is alternating and intermittent. The periods of flow in one direction should be of the shortest possible duration ($\frac{1}{1000}$th second). The flow in the opposite direction should be insufficient to stimulate the tissues.

Currents of which the interruptions and reversals are frequent should not be applied to the body with its strength unvaried. If this is done, the muscles will be tetanised, and prolonged contraction injures them. The current, whatever its modification may be, should be made to slowly wax and wane, gradually rising from zero to maximum and gradually falling from maximum to zero. The muscles will then relax between the contractions and their blood supply will be periodically replenished.

The other tissues will also be more effectively stimulated if the current is made to increase and diminish slowly and periodically. This may be brought about by including in the circuit a resistance that is continually varying. Such a variable resistance is shown in Fig. 38. It consists of a cylindrical or conical glass vessel filled with tap-water. A vertical metal rod that leads the current into the water is made to rise and fall (by means of clockwork or a small motor) within the water in the

cylinder and so interpose a column of water of varying length between the free end of the rod and the bottom of the cylinder through which the current leaves the vessel. Tap-water has a high resistance, so that when the wire is high up in the cylinder a greater length of

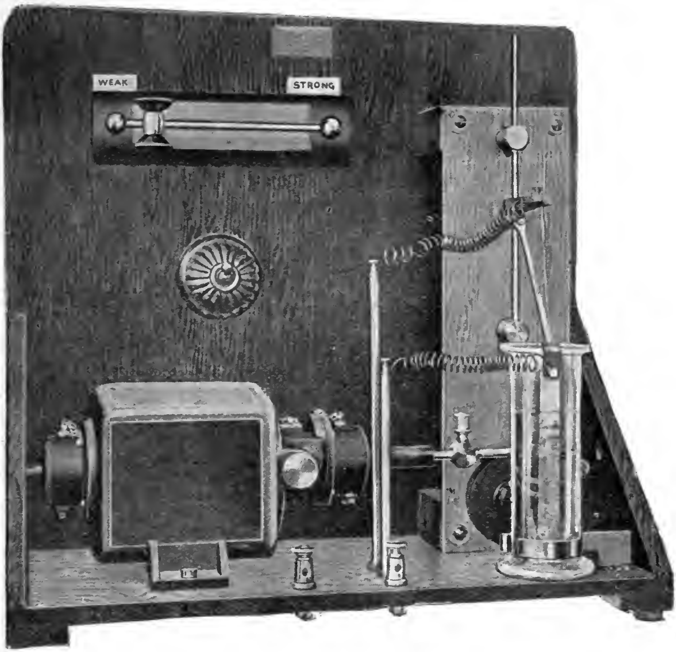


FIG. 38.—Rhythmic Resistance-varying Device, Motor-driven

water is interposed for the passage of the current. The current in the rest of the circuit is very weak, or stopped altogether. As the wire descends, so the current becomes stronger, and when the wire reaches the bottom of the cylinder the current is at its maximum strength. The rate at which the current rises to its maximum and falls

to zero can be varied, but usually the complete cycle (*i.e.* the rise to maximum and fall to zero) lasts from two to four seconds.

Current regulators working on this principle are very useful for electro-therapeutic work.

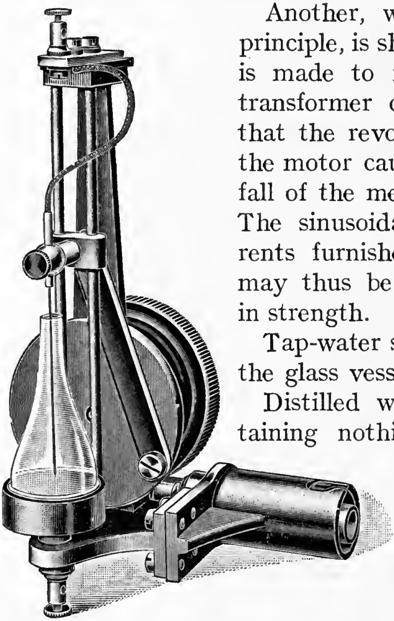


Fig. 39

Another, working on the same principle, is shown in Fig. 39. This is made to fix on to the motor transformer of the Pantostat, so that the revolution of the axle of the motor causes the slow rise and fall of the metal rod in the water. The sinusoidal and constant currents furnished by the Pantostat may thus be rhythmically varied in strength.

Tap-water should be used to fill the glass vessel.

Distilled water (*i.e.* water containing nothing in solution) will conduct the current scarcely at all, and it should contain just a sufficient amount of salt dissolved, so that when the wire rises to its highest position in the solution there shall be sufficient resistance interposed to just prevent the passage of current. Average tap-water contains a sufficient quantity of salts in solution. If more salts are added its resistance will be made too low, the current will at no period be cut off altogether, and there will be insufficient range of variation between maximum and minimum. If this device is used to vary a *constant* current, it will be noticed that the resistance of the tap-water rises

higher and higher. This is because the *constant* current decomposes the salts in solution and the number of ions diminishes. The resistance of the water may be lowered by cautiously adding, a drop at a time, 10% salt solution.

If there is no instrument at hand for producing rhythmic variation, a certain degree can be effected by moving one of the electrodes that convey the current into the body rhythmically over the skin, stroking the latter over the area that is to be treated, lifting it off at the end of each stroke.

The question may be asked: "Which current and which kind of rhythmic variation is the most suitable for stimulating the tissues of the body?" No definite answer can be given. It may be that each tissue will be better stimulated by one than by another. It can, however, be said for certain that currents which rhythmically vary have a more effective stimulant action than those which are applied without variation of strength. The selection will often depend upon which is available. The sinusoidal current rhythmically and slowly rising and falling between zero and maximum is particularly suitable for use in baths. If the sinusoidal is not available, the faradic current, made to wax and wane in the same way, may be used. A constant current, simply interrupted by a metronome, is used by Bergonié for its stimulating action in the treatment of infantile paralysis. A slow sinusoidal current is recommended by Dr Reginald Morton for the stimulation of unstriped muscle. Mention will be made, in the chapter on treatment, of the form of current most suitable for the different diseases and morbid conditions, under their respective headings.

It is possible that some of the tissues in the body are not stimulated or ineffectively stimulated by the methods at present available for applying electricity to the body.

It may be that each tissue requires its own appropriate electrical stimulus, regarding its strength, duration, rate of rise and fall, and so on. We know that striped muscle can respond to an extremely brief stimulus; muscle in a condition in which it shows a reaction of degeneration requires a much less short stimulus. Involuntary muscle requires slow stimuli—hence the recommendation of slow sinusoidal currents for treatment of morbid conditions of the alimentary canal.

Application to the Body.—When the treatment is applied locally electrodes like those already described for ionic medication may be used. They should be of large size, sufficient to cover the whole part requiring treatment.

The strength of current that a patient can bear depends upon its density or concentration at the places where it enters and leaves the skin. If small electrodes are used, small ports of entry for the current are provided, the current becomes unduly concentrated in the skin, the sensory nerves are strongly stimulated, and much pain is produced, even though the underlying muscles are receiving little current.

A large surface for entry of the current ensures the maximum current for the parts under the skin, with the minimum concentration or density in the skin. In other words, strong applications may be given without discomfort or pain.

The electrodes are made of absorbent cloth, such as lint or folded towel, soaked in warm salt solution (2% is strong enough), and felt-padded metal plates, similarly soaked, are placed in contact with them. The metal plates are connected to conducting cords leading from the source of current.

If rhythmic variation is to be effected by moving one of the electrodes over the surface, this electrode cannot,

of course, be of a size sufficient to cover the whole part requiring treatment. It should, however, measure three inches by three inches at least.

The importance of large electrodes and good contact between them and the skin has been emphasised on previous occasions. These requirements can be most easily fulfilled by using water as the electrode; the water is placed in a bath and the part to be treated is immersed in it. The application of electrical currents in baths has special advantages. The time occupied in fitting pads and removing them is saved. The part can be kept warm if hot water is used in the bath. Water acts as a perfectly fitting electrode of the largest possible size. The use of electrical baths must be considered in more detail.

Electric Baths.—These are made of porcelain or earthenware, or of some other insulating material, such as wood or fibre. They are made of sizes and shapes to take a single extremity, such as the hand and forearm, or leg and foot. Or it may be a full-length bath to take the whole body. The current is led into the water in the bath by means of a plate of carbon or metal that hangs from the edge of the bath and dips into the water. The plate and the water thus correspond to the pad electrodes that have hitherto been used. Now, in order to complete the circuit, we require a second electrode. If we are using the arm baths or foot baths, one of these may be used as the indifferent electrode, with one of the extremities immersed in the water. This is known as the unipolar method of applying the current, because there is only the one pole in each bath. With this arrangement *all* the current that is flowing in the circuit passes through the skin of the part immersed, into the limb, through the body and out by way of the limb in the indifferent bath electrode. With this arrangement,

therefore, other parts of the body share the treatment. Thus, if the forearm and hand are immersed in one bath, the leg and foot in another, the electrical treatment will be given to the hand and forearm, the upper arm and shoulder, trunk, hip, thigh, leg and foot. The skin of the parts that are not immersed will not receive much current, because the latter, having traversed it in the immersed parts, keeps to the underlying parts, as the resistance of the latter is low and that of the skin high.

With the arrangement described, electrical treatment may be given to any two of the extremities simultaneously. The trunk does not receive much stimulation, as it is the widest part of the circuit, and so the current density is low.

If it be desired to treat the four extremities simultaneously, two more baths are provided, to take the other limbs. The current can be sent from any two to the remaining two, or from any one to one or more of the remaining three. When the four extremities are receiving treatment simultaneously the trunk receives more stimulation, so that the whole body except the head can receive electrical treatment by this arrangement.

The Schnee bath is an arrangement of four baths, one for each extremity. It is shown in Fig. 40. By its means the current may be applied to two or more of the extremities, the trunk sharing it to a greater or lesser extent. The Schnee bath is useful for applying the electrical current to the whole body. There is, however, no stimulation of the skin except that of the parts immersed.

A switch-board is supplied with the Schnee bath outfit, so that the current that is available can be directed between any two, or more, of the baths. Either the faradic or the constant or the sinusoidal may be used.

In the case of the full-length bath, both electrodes are

immersed in the water, one at either end. The current passes between the electrodes and travels partly through the water, partly through the body.

FIG. 40.—Schnee Bath

The Full-length Bath.—As a means of applying electricity to the whole body the electric bath is the most agreeable and most efficient method we have. Large electrodes are placed at the head and foot, and the bath

filled with water at a temperature of from 98° to 100° Fahr., so as to cover the patient's shoulders when he is in.

The electrodes should be of metal and kept clean and bright. They should be $12'' \times 18''$ for the head, and $12'' \times 10''$ for the foot. A paddle electrode (Fig. 41) connected to one of the others is sometimes used by the operator to concentrate the current on any required part. It consists of a plate of metal, 4 inches square, mounted on the end of a long handle. It is connected to one of the other electrodes or it may replace it. A back rest made of a wooden frame with strips of webbing stretched across is required for the patient to lean against, and keep him from contact with the electrode. A similar one is not required for the foot. They should

FIG. 41.—Paddle Electrode

be made to fit the bath in which they are used or they will give trouble.

The full-length bath is a "bipolar" bath, as both electrodes are immersed in the water. The current will pass through the water from pole to pole, and some of it will pass through the body, the relative amounts depending on the resistance of the body and the resistance of the surrounding water. If there is much surrounding water, its resistance will be less than if there is a smaller quantity, and a greater share of the current will be taken by the water, leaving less for the patient. If salt were added to the water the resistance of the latter would be much lower and still less current would pass through to the patient. The amount of current passing through the patient is not the same in all parts of the body; the thick trunk has a smaller resistance than the narrower limbs, so that the former will take more of the current than the latter.

The full-length bath allows a greater general stimulation of the body than the Schnee bath, because in the latter only portions of the skin are immersed, whereas in the former the whole body is immersed. By means of the full-length bath it is possible to administer the largest quantity of electricity to the body, because the current is provided with the largest possible area of entry.

Current for Use in the Bath.—For the purpose of general stimulation of the body a valuable current is the sinusoidal. It should be applied so that it slowly and rhythmically varies in strength as it passes through the patient. The current may be taken from the main, using a static transformer when the main current is alternating or a motor transformer when it is direct. If there is no main supply at hand, the current from a battery of accumulators may be taken to the motor transformer. An alternative method is to use the faradic current, also rhythmically varied. The direct current from the main simply interrupted or simply reversed, as described on page 18, should never be sent directly through the bath, on account of the risks mentioned on page 52.

How the Electric Bath is given.—The bath should be filled with warm water at 99° or 100°, as measured by a thermometer, to a height sufficient to cover the shoulders. The wire connections should be tested to see that they are not loose and then the current is turned on to half strength. The operator should place his hands in the water so as to be sure that the current is flowing. The current is then reduced to zero again. The patient then enters the bath, and the current is gradually increased, little by little, till no more can be borne without discomfort. After ten to twenty minutes the current should be gradually reduced to zero, as before.

If languor or depression follows the bath it may mean that the current has been too strong, but some degree of fatigue is customary after an electric bath. It is temporary, and the patient should be forewarned of its likelihood. The patient should dress slowly, so as to cool off gradually, and rest for a quarter of an hour or so before going out into the open air. There is no special liability to catch cold after an electric bath, particularly if the patient walks home, which he should always do if possible.

At least twelve baths are required to produce a satisfactory result—but many cases arise in which it is found necessary to give a great many more. In no form of electrical treatment is it more necessary to exercise the utmost care than in everything pertaining to the electric bath; what would be of more or less trivial account under other conditions becomes a serious matter here. Any sudden change in the magnitude of the current, however small, has a very alarming effect on the patient. This is not unreasonable, considering how helpless he is when immersed in the water, and so placed that small changes have as much effect as large ones under other circumstances. Binding screws, conducting cords and the slider of the regulating resistance are all sources of trouble. They should be frequently inspected and tested, and all the apparatus should be personally examined by the medical man before each bath is given. He should turn the current on himself and not leave the room until he has turned it off, before the patient comes out. For female patients a bathing dress is necessary, as is also the presence of a nurse or maid in the room. The electric bath is a most valuable method of application; as a means of "general electrisation" it is the best at our disposal, and one of the most frequently used in this country. In America, "general faradisation" is the more popular method, and the electric bath is

apparently used to only a limited extent. This is a striking instance of the difference in the usual practice of the two countries.

General Faradisation or Galvanisation.—In the absence of an electric bath there is another method of bringing the whole body under the influence of the stimulating action of the electrical current.

This method is very fully described and illustrated by Rockwell, of New York, in the last edition of his work. The patient stands or sits on a large metal plate, which is covered with moist flannel, and if necessary kept warm by a hot-water bottle. One wire from the induction coil is attached to this plate, and the other to the active electrode. The latter may be a felt-covered metal plate with a handle attached for the operator. Sponge may be attached to the felt. It is moved over the head, neck, back, abdomen, arms and legs—from two to three minutes being given to each. The strength of current is not so strong as to be the least unpleasant. A pleasant feeling of vigour follows, with relief of fatigue and improved appetite and ability to sleep. There is no doubt as to the great value of the method, and it is the one to employ whenever the electric bath is not available.

The faradic current may be used alone or in combination with the constant current. This was suggested by Dr de Watteville and the treatment was called by him "galvano-faradisation."

CHAPTER IX

ELECTRICAL TREATMENT OF PARALYSIS

Electricity is a valuable agent for the treatment of paralysis and will, in suitable cases, give results that cannot be obtained by other methods. It is, however, of the first importance that correct methods of application should be employed, and it is the failure to recognise and adopt them that is generally responsible for the inability to obtain good results and the scepticism that still prevails in some quarters regarding the value of the treatment.

In any case of paralysis we have to consider, for the purpose of electrical treatment, the muscles, their nerves of supply, other tissues that are secondarily affected, and the cause that is responsible for the paralysis. In cases where the cause is irremovable and progressive, as, for example, in progressive muscular atrophy, paralysis agitans, etc., the degenerative changes in the nerves and the atrophy of the muscles will proceed and little can be expected from electrical treatment. But in cases where the cause can be removed or has ceased to operate, the nerves will recover their function, or regenerate, if their motor nerve cells have not been destroyed.

Nerves recover their function slowly, especially if regeneration has to take place. During this period the muscle is not only out of use, but under conditions that impair its nutrition and that of its nerves and its surrounding parts. By suitable electrical treatment the muscle can be exercised and the condition of the surrounding parts ameliorated. The changes that take

place in a paralysed limb may be briefly considered, together with the way in which electrical treatment produces beneficial results. When a muscle is paralysed as a result of injury or disease of its nerve (lower motor neuron) the following changes take place and persist till the nerve has recovered its function.

The muscle ceases all work. It is not even a *resting* muscle, for there is some degree of continuous contraction or tone in a resting muscle, and chemical changes are still going on in it. But when there is a lesion of the lower motor neuron, the muscle ceases work entirely. It hangs loosely from its extremities, supported by the skin. Its circulation becomes feeble in the extreme, and the blood supply to the adjoining parts is much impaired. The temperature is lowered and the muscle cannot shiver itself warm. The skin becomes blue and cold, and chilblains develop. The growth of the bone is retarded.

If the nerve fibres regenerate there may be some recovery of function by the muscle, but less in proportion to the length of time during which the muscle has remained in this abnormal condition.

When the lesion causing the paralysis is in the upper motor neuron the condition is less bad when the muscles have passed into a spastic condition, for then there is increased tone, and chemical changes continue, and the circulation is not so impaired. But the muscle cannot contract and its fibres may be to some degree replaced by fibrous tissue as a result of loss of active use, before voluntary power returns. And during the time before the muscles pass into the spastic state their condition is that of muscles in flaccid paralysis.

To prevent these changes a proper circulation must be maintained in the limb, and the muscles and nerves must be artificially stimulated so as to make them work and improve their blood supply. No method of treatment

can bring this about more effectively than electrical currents properly applied in the way to be described. Every part is traversed by the current, and every nerve fibre and muscle fibre is stimulated, while all the tissues benefit from the improved blood supply.

The points to which attention should be particularly directed when giving electrical treatment may be considered in order.

The Current to be used.—The use of an unmodified constant current produces but little stimulation, as shown by the experiments of Debedat (page 121). The current must therefore be modified, so as to bring about the most effective stimulation of the tissues.

It is commonly taught that if the paralysed muscles show normal reaction the faradic current (*i.e.* the current from an induction coil) should be used, while if they show the reaction of degeneration, the galvanic current should be used. This choice of current is probably based on theoretical grounds. Since the times of Duchenne and Remak, each current has been regarded as superior to the other by different observers. The galvanic is the only current that will cause contraction of a muscle showing the reaction of degeneration, but it has to be proved that it is necessary to cause muscles to contract when treating them for paralysis. It is possible that one current may be more suitable for some tissues in cases of paralysis, another current for others.

Whichever current be chosen, it is essential that it should be continually varying in strength. Varying currents have a greater stimulating action on the tissues than steady currents and increase their metabolism to a greater extent. A constant current, *unvarying* in strength, such as is so commonly supplied to baths, has little or no value in the treatment of paralysed muscles. A faradic current, *unvarying* in strength, tetanises,

fatigues and asphyxiates the muscles (if they respond to this current), and does actual harm.

Some experiments were carried out by Debedat to determine the influence on growing muscles of different electrical currents applied in different ways. It was found that the rhythmically varied faradic current caused the largest growth (40%); the rhythmically varied galvanic current caused an increase by 18%. These currents were both allowed to flow, during each application, intermittently, periods of flow and periods of rest alternating, each lasting for one second. If the currents flowed continuously without rhythmic variation, quite different results were obtained. The muscles treated by the unvarying galvanic current showed but a slight increase in size; those treated by the faradic current with strength unvaried, diminished in size and the muscle fibres were damaged, as shown by microscopic examination.

These experiments show the importance of rhythmic variation in the strength of the currents used for their influence on growing tissues, and it is reasonable to conclude that rhythmically varying currents are more effective in the stimulation of paralysed muscles and nerves—a fact which is borne out by clinical experience.

The modifications and variations of the electric current are described in Chapter II., and are summarised in Chapter VIII. It is a very difficult task to decide which of these is the best. If the choice lies between the faradic and galvanic, we may select the galvanic current for treatment of muscles showing the reaction of degeneration, and the faradic current for muscles showing reactions of the normal type.

When the faradic current is used it should be made to vary its strength by the water resistance method (page 106). Or it may be sent through a metronome interrupter, which is made to swing so that the current

flows for periods of one second each, followed by a period of rest of equal length. The metronome interrupter produces *sudden* contractions, while the water resistance produces *gradual* contractions. The latter are more pleasant.

When the constant current is used it should be interrupted periodically by the metronome (simple intermittent current), so that periods of flow and no-flow follow one another, each lasting one second.

The sinusoidal current is very valuable in the treatment of paralysis. Not only does it produce good results, whether the muscles show the reaction of degeneration or normal reactions, but it is the simplest to use, and when applied to arm or foot baths or full-length baths very little attention is required. The sinusoidal current is applied to eight baths in the electrical department at St Bartholomew's Hospital.

When no device for rhythmic interruption or variation is available the effects may in some degree be produced by moving one of the electrodes to and fro and on and off the skin.

The Electrodes.—These are of the same design as those previously described, pads of folded lint or towel, covered by felt and metal plate (Fig. 33). They should be large enough to cover the group of muscles requiring treatment. When the rhythmic variation has to be effected by moving one of the electrodes over the skin, this electrode cannot be of a large size ; it should, however, measure at least three inches by three inches. The small padded disc or button so frequently supplied in the induction coil cases should not be used, as they are much too small. Only a small current can be applied through small electrodes, and the attempt to use a current of adequate strength will cause unnecessary pain.

The use of small electrodes in the treatment of paralysis

in children is responsible for the statement that electrical treatment of infantile paralysis is impracticable on account of the pain which it produces.

When the paralysis is general, or when it involves an extremity, the best electrode is water—in the Schnee bath or full-length bath, because the largest current can be given with the least amount of sensation. The parts immersed are kept warm, they are surrounded by the water, which acts as a perfectly fitting electrode, and the time that would be occupied by applying the usual electrodes is saved. This saving of time is matter for consideration in hospital practice.

If the lower limbs are to be treated, the full-length bath may be used, the patient sitting up, with only the lower limbs and pelvis immersed. In the case of the upper limbs and shoulders the Schnee bath (page 112) may be used. The Schnee bath may also be used for the lower limbs and also for the whole body.

With regard to the *situation* of the electrodes, they should be placed so as to include in the part traversed by the current, not only the affected muscles, but also the affected nerves, and, when possible, the cause that is responsible for the paralysis. Thus, for example, in paralysis of the extensors of the upper limb caused by pressure or other injury to the musculo-spiral nerve, one electrode should cover the posterior aspect of the fore-arm, and the other should be placed around the upper arm and shoulder, so as to cover the region of the injury. Or when the Schnee bath is used the opposite arm should be immersed in the other arm bath, so that the current, on its passage from bath to bath, will traverse the seat of the injury.

The situation of the electrodes will vary in each case, according to the part paralysed, and the cause responsible, and the matter will be further considered under the headings of paralysis of different regions.

The Strength of the Current and the Duration of the Treatment.—At the present day stronger applications are made and the duration and frequency are increased, and evidence goes to show that better results are obtained. Bergonié has increased the length and strength of the electrical treatment of infantile paralysis, and he now gives two applications daily, each lasting thirty to sixty minutes. No fatigue occurs, and nothing but good results. In busy hospital practice, treatment cannot be given so frequently, as a rule, and two applications each week, lasting for thirty minutes each, may be given to out-patients. In private practice the consideration of expense will sometimes prevent a patient coming for treatment with sufficient frequency. Under these circumstances it may be advisable for the patient to receive treatment in his own home, where it may be given by a nurse or by one of his relatives or even by himself, under instruction and supervision by his doctor. The faradic current may be used, and an induction is the least expensive to buy. The galvanic current, from a portable battery, may be used, but the apparatus costs more. Portable batteries may sometimes be had on hire. Whichever current is used, it should be applied with its strength rhythmically varied, and the readiest way for the patient to do this is to use a movable electrode in the way previously described. Home treatment may be given for fifteen minutes twice daily.

Treatment of Peripheral Nerve Paralysis.—In this chapter will be considered the electrical treatment of paralysis due to lesions of the peripheral nerves, and to anterior poliomyelitis in children. The treatment of paralysis due to diseases of the central nervous system will be found in Chapter XIV.

The value of electricity in hastening recovery after injury or disease of the peripheral nerves is now very

generally accepted. Though it is maintained by some that the cases would recover quite as rapidly without treatment, many arise which remain stationary for a considerable period of time before electricity is applied, and then begin to improve rapidly.

The paralysis may be due either to injury or disease of the nerve. Injury of the nerve trunks are most common in those placed superficially, and the injury may be of any degree varying between slight pressure, causing numbness, to bruising, laceration and division, with loss of motor power and sensation in the localities supplied by the nerve or nerves implicated.

They occur more often in the shoulder and arm, and all cases are most interesting from the diagnostic standpoint. Falls, blows, dislocations, pressure as from the use of a crutch, or falling asleep with the arm over the back of a chair may produce a musculo-spiral paralysis. Incised wounds about the wrists from broken glass or other cause frequently result in division of the ulnar or median nerves. The first thing to be done in any case of division is to find and suture the divided ends—or if the paralysis is the result of pressure by cicatrical tissue or callus it must be freed from its surroundings. The case will be referred for electrical treatment at a later date, and if tested, reaction of degeneration will be found in the muscles supplied by the injured nerve.

The paralysis may be due to *disease* of the peripheral nerves. Alcohol, metallic poisons (such as lead and arsenic), gout, syphilis, sepsis and the specific fevers are common causes. Often there is no discovered cause and we speak of a " rheumatic " neuritis. If a mixed nerve is affected, either by disease or injury, pain may be severe, or, on the other hand, it may be slight or absent. If pain is present it is a good plan to commence the treatment by ionising the painful regions with salicylic

ions, and leaving the usual treatment till the pain has subsided or lessened.

Facial Paralysis.—The cases that respond best to electrical treatment are those in which the paralysis is due to simple inflammation and swelling of the nerve trunk—cases of Bell's palsy. Here the exciting cause of the neuritis, whatever it may be, disappears in a majority of cases, or ceases to act, and we are left with the damaged nerves and paralysed muscles. The treatment may be carried out in the following way:—If the muscles show the reaction of degeneration, the constant (galvanic) current is to be used. One electrode is connected to the positive pole of the source of current. The hand is placed in contact with it. This is the "indifferent" electrode. The active electrode, made of a metal disc, two inches in diameter, padded with felt (of the same kind as that described and illustrated on pp. 140, 141), is soaked in a 2% solution of sodium salicylate and connected to the negative pole of the source of current. It is then stroked across the face, and at the same time the current should be turned on and increased till it is as strong as can be borne. The electrode should be stroked across the face successively over the main branches of the nerve starting behind and below the pinna (from the region where the nerve leaves the stylo-mastoid foramen) and ending at the middle line of the face. Here the electrode should be lifted off the skin, so as to interrupt the current, and then be replaced over the foramen and again stroked across the face.

The stroking action causes variation in the strength of the current and stimulation of the muscles and nerve. Salicylic ions migrate through the skin, and they may have a beneficial influence on the inflamed nerve and, possibly, some action on the agent responsible for the neuritis, if this be some micro-organism.

Another method of treatment is to cover the whole of the affected side of the face with a pad, cut to the correct shape, and soaked in 1% salicylate of soda. This pad is connected to the negative pole and secured to the face. By placing a rhythmically varying resistance in circuit the current is made to wax and wane, or is suddenly interrupted and resumed.

The first method is the simplest and is easier to apply. The treatment should be given at least twice each week, and for twenty minutes each session. It may be given more frequently—every other day, or even daily if there is no erythema or tenderness remaining from the previous treatment.

If the facial muscles do not show the reaction of degeneration, the faradic current will be sufficient. It can be applied in the same way. The active electrode is soaked in dilute salt solution. A dry wire metal brush may be used instead of the moistened padded disc, and stroked over the dry skin. This produces strong *sensory* stimulation of the skin of the face and influences the facial nerve and its muscles reflexly.

Cases of facial paralysis due to inflammation spreading to the nerve from the middle ear will not be improved until the latter region has received appropriate treatment. Electrical treatment is less likely to produce favourable results in these cases.

Facial paralysis due to a lesion in the upper motor neuron is more likely to recover spontaneously than those in which the lower neuron is involved.

Paralysis of the Shoulder Muscles.—The *trapezius* and *sterno-mastoid* are frequently paralysed, either singly or both together. To carry out electrical treatment when the trapezius or when both muscles are paralysed, one electrode should be fixed in the posterior triangle of the neck, overlapping the sterno-mastoid when this muscle

is also paralysed. The other electrode, a metal disc three inches in diameter, padded with felt, should be stroked over the trapezius from insertion to origin, passing, in order, over different parts of the muscle. The electrode on the neck overlies the spinal accessory nerve, so that the latter is included in the treatment.

When the paralysis involves the sterno-mastoid alone, an indifferent electrode may be placed on the back, while the active electrode may be stroked along the muscle and nerve.

When the paralysis is due to a simple neuritis of the spinal accessory nerve, the electrode overlying the nerve may be soaked in 1% salicylate solution and connected to the negative pole. The other electrode is then soaked in salt solution. When the paralysis is due to inflammation spreading to the nerve from suppurating tuberculous glands, the latter must receive treatment before electrical treatment of the muscles can be carried out with any prospect of success. When due to injury of the nerve, similar methods may be employed, but the nerve, if it has been accidentally divided during surgical operation, must be sutured. When due to spinal poliomyelitis, similar treatment may be given on the chance that some part of the nucleus of origin of the nerve has escaped destruction.

Serratus Magnus.—Paralysis of this muscle may result from injury to the posterior thoracic nerve as a result of blows on the side of the neck or an injury to the shoulder region. It may be the result of neuritis. For electrical treatment one pad should be fixed in the posterior triangle. The other should be stroked over the serrations of the muscle.

The Deltoid.—Many cases of paralysis of the muscle are encountered. The paralysis may be the result of blows on the shoulder causing injury to the circumflex nerve in its course through the muscle. Or the nerve

trunk may be compressed by pressure within the axilla caused, *e.g.*, by a crutch-head, or by injury or dislocation of the shoulder. The teres minor is paralysed with the deltoid when the injury involves the nerve trunk before it enters the muscle.

For electrical treatment of the paralysed deltoid, it is advisable, when the paralysis is due to injury, and the injury is recent, to surround the limb in the region of the injury by one electrode, place the other electrode around the forearm and direct the galvanic and afterwards the faradic or sinusoidal currents between the two electrodes, rhythmically varying in their strength by means of the instrument described on page 106. The galvanic current will probably have some action in helping the absorption of effusions into the region of the injury. Afterwards the sinusoidal or faradic current may be used. It may be applied in the Schnee bath, the arms immersed in their respective vessels. Another method is to immerse the forearm of the affected side in the Schnee bath and to apply the other electrode to the shoulder, fixing it there, or using a movable electrode and stroking it over the region of the muscle. In the latter method, no rhythmic current regulator is needed.

The Spinati.—Of the other shoulder muscles, the spinati are more frequently found paralysed than the latissimus dorsi, pectorales, teres major and subscapularis which usually escape. The spinati are paralysed as a result, usually, of injury of the suprascapular nerve. Electrical treatment is carried out by fixing one electrode, connected to one pole, in the posterior triangle ; the other electrode may be moved over the affected muscles. The spinati are frequently paralysed with the deltoid.

Paralysis of the Arm Muscles.—The muscles supplied by the musculo-spiral nerve and its branches (triceps, brachio-radialis, supinator brevis and the extensors of the

wrist, fingers and thumb) may be paralysed as the result of injury or of disease of the nerve. The injury may result from dislocation of the head of the humerus, in which case other nerve trunks may be injured as well, or it may result from fracture of the humerus or involvement of the nerves in the callus. The triceps will escape if the nerve trunk is injured below the origin of the branches to this muscle. The nerve trunk may be damaged by pressure from a crutch-head or the back of a chair.

Apart from injury, the muscles may be paralysed from neuritis. Chronic lead poisoning and alcoholic excess are the common causes of this neuritis. The triceps usually escape, leaving the forearm muscles paralysed, so that wrist-drop is produced. In lead poisoning the brachio-radialis is said to escape.

Before electrical treatment is commenced the cause of the paralysis must be removed wherever possible. For the treatment one electrode is placed on the shoulder, the other on the posterior aspect of the forearm. The paralysed muscles should be supported by a splint applied to the anterior aspect of the forearm, so as to prevent their extension by the antagonistic muscles. The splint should also be worn between the sessions of treatment.

An alternative method is to use the Schnee bath and direct the current from arm to arm.

The common causes of paralysis of the muscles supplied by the ulnar and median nerves are injury in the region of the elbow, or shoulder, or wrist. The injury may be a dislocation of the joint or fracture in its region : other nerve trunks in the neighbourhood may be simultaneously injured. In the region of the wrist an incised wound is the common cause. Pressure from a crutch-head may also injure the ulnar nerve as well as the musculo-spiral. A cervical rib may cause pressure on the first dorsal nerve root. In this root run some of the fibres that ultimately go to form the ulnar and median nerves ; ulnar and

median paralysis may therefore be caused by pressure from a cervical rib. The intrinsic muscles of the hand are usually affected: sometimes also the forearm muscles supplied by the nerves mentioned.

Injury or disease of the ulnar nerve results in loss of power, wasting and, often, reaction of degeneration in flexor carpi ulnaris, flexor profundus digitorum (inner half), the hypothenar eminence, all the interossei, two inner lumbricales, adductor pollicis and inner head of the flexor brevis pollicis. Later on the proximal phalanges become over-extended, and the distal phalanges flexed, due to the unopposed action of the long flexors and extensors. The hand becomes thin and flat, and the characteristic deformity known as the *claw hand* is produced. There is also loss of sensation in the little finger, ulnar half of the ring finger, and corresponding part of the palm.

The median nerve is sometimes divided at the same time as the ulnar. If injured or diseased there is paralysis, wasting and, often, reaction of degeneration in the abductor pollicis, opponens pollicis, and outer head of the flexor brevis pollicis.

There is wasting of the thenar eminence, and the thumb is everted with the nail facing dorsally. Sensation is lost in thumb, index and middle fingers and half of the ring finger and corresponding part of the palm. These are the events that follow a lesion of the median nerve in the region of the wrist. When the nerve trunk is injured or diseased in the forearm or higher up, the flexors of the fingers and thumb, radial flexor of the wrist, palmaris longus and pronators are paralysed in addition. The treatment of paralysis of the median and ulnar nerves is carried out on the same lines as that of the musculo-spiral.

Erb's Paralysis.—Cases of paralysis of a group of

muscles which does not correspond to the distribution of any single nerve trunk are not uncommon. In these the lesion will be found very often in the nerve root as it comes from the spine and before it reaches the plexus. This is known as "root paralysis." If the muscles supplied from the different nerve roots are known, the operator will easily manage to refer them to their proper origin. One of the most common of these is that known as Erb's paralysis. It results from disease or injury of the fifth and sixth cervical roots before they join the brachial plexus. The muscles affected are the deltoid, biceps, coraco-brachialis, brachialis-anticus and brachio-radialis.

All these muscles are thrown into action in the normal subject by stimulation of Erb's point (see Plate I.).

It will be also noticed that three nerve trunks are represented in the above-mentioned group of muscles—viz. the circumflex supplying the deltoid, the musculo-cutaneous supplying the coraco-brachialis, brachialis-anticus and biceps and the musculo-spiral supplying the brachio-radialis. The position of the arm and hand in this condition is very characteristic. The arm hangs straight down by the side, and the hand is rotated inwards, so that the palm is looking backwards. It has been humorously referred to as the "policeman's tip" position, which is a fairly accurate description of it. It has also been called "obstetrical" palsy, as it has often resulted from traction on the arm in difficult labour.

The prognosis in any case depends on the nature and severity of the lesion producing it. If due to pressure and involvement by malignant disease it would, of course, be very unfavourable. If due to injury at birth the extent of the injury will determine the nature of the prognosis. In severe cases where the nerves are lacerated or torn out from the cord recovery is practic-

ally impossible. Most cases fortunately are less severe than this, and recovery to a greater or less extent is the rule.

It will be assisted and hastened by electrical treatment. Treatment must be kept up regularly and persistently so long as improvement continues.

One electrode should be fixed to the posterior aspect of the neck, so as to cover the cervical enlargement. The other should be stroked over the shoulder, anterior aspect of the arm and radial border of the forearm.

The mother or nurse should be instructed to massage the arm once or twice daily for from five to ten minutes at a time, and, while doing so, to hold the limb so as to correct the faulty position. It is also advisable to protect the arm from cold as far as possible, especially in the winter months.

It is important to remember that great care is to be taken in dealing with children, so as not to frighten them by using too strong a current at the beginning. Indeed it is a good rule at the first application not to turn on any current at all, but to have everything else arranged as usual. This gains the child's confidence, and at the next application a very mild current is used. This is gradually increased on subsequent occasions until a sufficiently strong current is applied.

Peripheral Nerve Paralysis in the Lower Limb is much less common than in the upper extremity. It may be caused by injury in the region of the knee joint or penetrating wounds of the sciatic nerve. A neuritis of the sciatic nerve trunk or of its cords of origin may be the exciting cause.

The electrical treatment is carried out on the same lines as for paralysis in the upper limb. The full-length bath is very convenient. The Schnee bath is also useful. If there is foot-droop, a support should be worn so as

to prevent passive stretching of the paralysed muscles. In the Schnee bath the support may be effected by resting the sole of the foot on the bottom of the bath with the leg vertical. In the full-length bath the foot may be pressed against the vertical metal electrode at the foot of the bath.

In cases of paralysis of the sciatic nerve where the onset is sudden with much acute pain, the treatment should be commenced by ionisation of the nerve with salicylate. When the pain is subsiding, the treatment may be changed to application of the sinusoidal current, rhythmically varied, in the long bath.

Treatment of Infantile Paralysis.—This is the most common form of paralysis met with in the electrical department of a hospital, and fortunately is one for which a great deal can be done. The seat of the disease is in the anterior cornu of the spinal cord, where a more or less extensive destruction of the ganglion cells is found. Owing to the fact that the nucleus of origin of the motor nerve of any muscle extends through one or more segments of the cord, it is impossible for any localised lesion to paralyse any single muscle exclusively, and also, especially if the lesion is small, it is unlikely that any large muscle will be completely deprived of the influence of the nucleus of origin of the nerve which supplies it. Part of its nucleus may be destroyed, while other parts are less damaged or even uninjured.

The teaching that the ganglion cells are either destroyed or uninjured—rendering treatment futile in the one case and unnecessary in the other—is incorrect and harmful. The experience, extending over some years, obtained in the Electrical Department at St Bartholomew's Hospital is a direct refutation of it. No case is so extensive or so severe that no good will result from proper and persistent treatment.

The state of the muscles in any case will depend on the severity of the original attack and on the time that has elapsed before coming for electrical treatment. It may vary from slight weakness without wasting or loss of voluntary power to complete paralysis with wasting and loss of response to all electrical or other stimuli. Different degrees may be found in the same case, and while the milder cases tend towards spontaneous recovery, it may be safely claimed that without electrical treatment the recovery is slower and less complete. In the more severe cases where there is wasting and reaction of degeneration, the tendency to spontaneous recovery is very slight, but here electricity is able to do a great deal to improve matters.

When the lower limbs are affected, as is usually the case, the treatment may be carried out in one of two ways. In one, the patient is immersed in warm water in a bath of suitable size. The current may be either a faradic or a sinusoidal; both must be rhythmically varied. The weakest application must be made during the first session, and stronger applications should be made subsequently. It is very important that the child should not receive strong applications at the beginning of the treatment, when it is unused to it. The application of the treatment in baths is the pleasantest way and children will rarely cry when they are receiving it. There are two baths in the Electrical Department of St Bartholomew's Hospital for the treatment of infantile paralysis. The mothers bring their children up with great regularity, and the good results that follow correctly applied electrical treatment are seen.

When treatment is commenced chilblains, if present, disappear, the skin loses its blue colour and the limb becomes warm, even though, at this stage, no voluntary power of the muscles may have been regained. If the anterior horn grey matter has not been damaged

beyond repair, some voluntary power will be recovered and reactions of the normal type will return.

The best results are seen in hospital practice, where question of expense does not arise to cut short what is always a long course of treatment. Where expense has to be considered, an electric bath may be improvised for home treatment from a wooden tub or earthenware foot bath. It is filled with water, and a current from an induction coil is sent through the water by way of two metal plates, one placed at each end of the bath. Rhythmic variation can be effected by slowly sliding the secondary coil over the primary or pulling the metal sleeve slowly backwards and forwards over the iron core.

This may be carried out at home and the mother or nurse instructed in all the details of the treatment, but where possible some part of the treatment should be carried out by the medical man, as this ensures thoroughness in at least part of the treatment, and also makes it more easy to keep in touch with the progress of the case.

Another method of electrical treatment of infantile paralysis of the lower limbs is used by Bergonié. One electrode, in the form of a large, well-fitting pad moistened with warm saline, is placed under the back. The other is wrapped round the soles and the rest of the feet. The faradic current is used when the muscles show reactions of the normal type ; the galvanic current when there is reaction of degeneration. Either current is interrupted rhythmically by a mercury metronome.

Massage and manipulation constitute a useful accessory treatment. It is a mistake to say that massage can replace properly applied electrical treatment and procure equally good results. This is particularly true in reference to cases showing blueness of the skin, with chilblain and ulcers. The application of the electrical treatment in the bath causes their prompt disappearance, while

massage is generally ineffective for this condition of the skin.

The objection is raised that the electrical treatment stimulates the antagonist muscles (if they are healthy) to contract, so that those which are paralysed are passively stretched. This can be avoided by applying a suitable splint so as to support and fix the part moved by these muscles. It is to be remembered that if these paralysed muscles show the reaction of degeneration, and if the galvanic current is used to treat the paralysed limb, the healthy antagonists will give a quick twitch, while the paralysed muscles will give a sluggish contraction which will long outlast the quick twitch, thereby causing a passive stretching of the *healthy* muscles!

In cases of infantile paralysis of the upper limb the same method of treatment as described for Erb's palsy may be used.

Periodic examinations are to be made of the condition of the muscles by electrical testing. The electrical reactions will afford a good guide as to the progress of the case. In the most severe cases, in which, at the beginning no reactions of any kind could be obtained, the first sign of improvement may be a very weak, sluggish contraction. It often happens that the return of voluntary power precedes any marked change in the response to electrical stimuli.

It is useless to commence treatment of infantile paralysis unless prepared to persevere with it. It should be given at least twice weekly, or, better, four times or six times, when possible. Bergonié treats his cases twice daily, for half-an-hour to an hour. There is no fatigue produced and the best results are obtained.

The treatment of infantile palsy should be extended over a period of at least six months, and left off only when it is evident that no improvement has taken place for the same period of time.

CHAPTER X

THE USE OF THE ELECTRICAL CURRENT FOR TESTING THE REACTIONS OF MUSCLE AND NERVE

THE physiological response of muscle and nerve to electrical stimulation may be profoundly modified in cases of disease of these tissues. The determination of the nature of the response is known as the "testing of the reactions," and it affords information that cannot be obtained in other ways, the diagnosis in some cases depending upon it. The testing of the reactions of muscle and nerve forms, therefore, an important part of the investigation of cases of paralysis. The reactions sought are the contractions that follow stimulation, first by the faradic current (known also as the *interrupted* current), second, by the galvanic current (known also as the *continuous* or *constant* current), both currents being applied in succession to the muscle itself and to the nerve trunk that contains its motor fibres.

The Reactions of Normal Muscle and Nerve.—When a muscle or its motor nerve is stimulated by the faradic current it will remain in continuous contraction or "tetanus" so long as the current flows. The contraction is continuous, because this current provides a number of stimuli repeated in rapid succession. The muscle being able to contract in response to each stimulus has not time to relax in the very short interval between two successive stimuli.

When the muscle or its motor nerve is stimulated by the galvanic current, the muscle makes a single twitch at

the moment when the current *commences* to flow. No contraction is seen while the current is actually flowing. A second twitch is seen at the moment the current ceases to flow (if the current is sufficiently strong). These responses—a continued contraction when the muscle or its motor nerve is stimulated by the faradic current, and a single twitch when they are stimulated by the galvanic current—are the responses of normal muscles and nerves and are spoken of as "reactions of normal type" or "normal reactions." They are altered in disease.

In order to test the reactions we require an induction coil, a source of constant current, two electrodes and the necessary conducting wires. A convenient arrangement is a switch-board fixed to the wall or a movable table, to which are attached a rheostat, from which a constant current of suitable strength may be shunted from the main, and an induction coil which may be worked by the current from the main. By means of a switch either the faradic or the constant current may be diverted to the patient by way of two terminals fixed to the board. A milliampere-meter is provided, so as to indicate the strength of the constant current that is being used. A commutator is provided, so that the direction of the latter current may be reversed, if desired. A switch-board of the type described is shown in Fig. 21.

If there is no main supply, or if the apparatus is to be portable, the combined battery shown in Fig. 42 may be used. Inside the case are an induction coil and a battery of dry cells. It is important that a coil of suitable design should be used if accurate results are to be obtained and the testing is not to be painful. The subject of induction coil current is considered on page 31, where the importance of using a proper coil is further emphasised.

Two electrodes are required. One, the "indifferent" electrode, is of the type described and figured on page 78;

it should measure six by three inches. The other, the "active" or "testing" electrode, is a metal disc three-quarters of an inch in diameter, covered with chamois leather, mounted on a handle, to which is fixed a closing-key (Fig. 43) by means of which the current may be sent through the patient when wished.

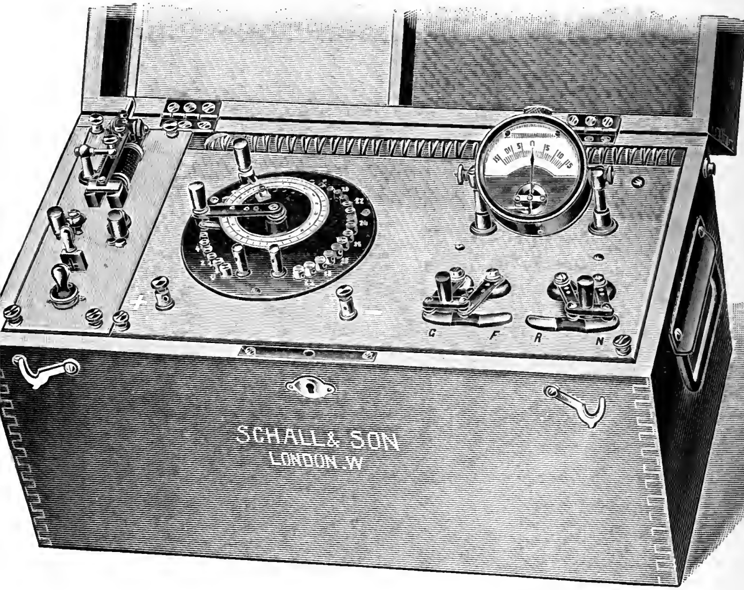


FIG. 42

The electrodes are moistened with warm salt solution (about 5% strength). The indifferent electrode is placed on some part of the body away from the muscles that are to be tested. When the upper limbs and shoulder girdle are to be tested, it may be placed over the sternum. In the case of the lower limbs it may be kept in the same situation or placed behind the hips. When the intrinsic muscles of the hand or foot are to be tested the in-

different electrode is better placed on the palm or sole. When testing the face or neck muscles it may be placed under the palm.

The testing electrode is placed over the muscle or nerve of which the reactions are required. The skin in contact with either electrode should be well moistened with the salt solution before beginning the test.

In carrying out the test the faradic should always be used first.

The operator should first grasp the limb to be tested and pass the current through his own hand, moistened with salt solution, as well as through the patient's limb. This not only gives the operator an idea of the

FIG. 43.—Testing Electrode. The chamois-leather-covered metal disc screws on the end. It is not shown in the figure.

strength of the current, but has a reassuring effect on the patient. Strong currents are seldom necessary in electrical testing. All that is required is enough to produce a distinct contraction. The current should be just strong enough to produce a distinct contraction of the operator's dorsal interossei when grasping the patient's limb. This strength will be suitable for most of the limb muscles, but will probably have to be increased when testing the intrinsics of the hand and foot, with the indifferent electrode on the palm or sole. The increase is necessary on account of the high resistance of the thick skin of the sole and palm. Muscles that lie close to the surface, like the facial muscles, require weaker currents; those that lie farther away require stronger currents. If there is a thick layer of subcutaneous fat, a stronger current will be required.

The various muscles that are to be tested are

stimulated in turn with a current that is just strong enough to produce a distinct contraction.

It is assumed that the operator has a knowledge of the anatomy of the muscular and nervous systems, including the action and nerve supply of the individual muscles. Such knowledge is absolutely essential if the examination is to have any value.

It is found that when stimulating any normal muscle there is a point where the contraction is greater, or, in other words, when the minimal contraction is obtained with a smaller current, than when the electrode is even but slightly moved from this point. This is called the "motor point" of the muscle. Each muscle has its motor point, and it is found to correspond to the spot where its motor nerve enters the substance of the muscle. A thorough knowledge of motor points enables one to carry out a test with the smallest possible amount of current and consequently the least discomfort to the patient. Speaking generally, the motor point is situated about the middle of the body of a muscle. Thus the beginner, by calling up a mental picture of the muscle which he wishes to stimulate and placing the active electrode over the middle of its body, will be either on the point or so near that very little exploring will discover it. This does not apply to all the muscles, but it does apply to a great many, and a knowledge of this fact is a great help and encouragement to the beginner. It is important to point out that it is not necessary, even if it were always possible, to throw the whole of the muscle into strong visible contraction. Some muscles do contract strongly and visibly with moderate currents ; of this, the biceps in the arm is a good example. The evidence of the contraction of others is obtained by placing the finger lightly over the tendon at the moment of closing the current. In this way the slightest contraction becomes manifest. The muscles of which the tendons are

gathered about the wrist and ankle are examples. Others, again, are only manifest when the characteristic action of the muscle takes place, such as the supinator brevis.

Muscles which are too feeble to produce their characteristic action can only be detected by some slight movement on the surface near the electrode. The plates following page 160 show the position of the motor points—they should be referred to continually, until the operator is perfectly familiar with them.

After testing the muscles with the faradic current, the galvanic (constant) current is used. The testing electrode is made the *kathode* by connecting it to the negative pole of the source of current. A preliminary trial of the strength of the current should first be made in the way described above, and a current should be used that is just sufficient to cause a twitch when the current starts. It is of importance to use the smallest galvanic current, because this current causes a more painful sensation than the faradic, and if strong it may be unbearable. It is found when testing with galvanic currents of increasing strength that a twitch is first noted only at the moment when the circuit is closed and the current is started. It is only when the current has been much strengthened that a twitch is also noticed at the moment when the current is interrupted. It is noticed, further, that the twitch seen when the circuit is closed occurs sooner (*i.e.* with weaker current) when the testing electrode is the *kathode* than when it is the anode. These twitches are known as the " kathodic closure contraction " (KCC) and the " anodic closure contraction " (ACC). The other twitches occurring when the circuit is opened and the current interrupted are called the " anodic opening contraction " (AOC) and the " kathodic opening contraction " (KOC).

The *relative* strength of the current required to produce

each of these twitches is seen in the table below. The *actual* values depend in each case on the thickness of the overlying tissue; when this is thicker a stronger current will be required:

KCC	2
ACC	3
AOC	3·5
KOC	15

When testing the muscles and nerve trunks with the galvanic current, the latter should be sufficiently strong to produce an evident contraction with the weakest current when the testing electrode is the *kathode* and at the moment when the current is started by *closing* the circuit. That is to say, the testing current should be just strong enough to produce a distinct KCC. The strength of this current should be read on the milliampere-meter when the needle has come to rest.

When stimulation of a motor point causes contraction of a muscle, the contraction is not due to the stimulation of the muscle substance, but to the stimulation of the motor nerve at the point where it enters the muscle; this is because motor nerve is more excitable than muscle. When the nerve has lost its excitability the muscle will then be stimulated directly, not indirectly through its nerve. It will then be found that there is no "motor point," and that contraction can be produced by stimulating any part of the muscle, especially its tendinous end, because there the muscle is nearest to the surface.

It will well repay the student to practise testing his own muscles, so as to gain familiarity with the position of the motor points, and to recognise the contraction of individual muscles and note the behaviour of the muscles when the different nerve trunks are stimulated. When using the galvanic current the readings of the milliampere-meter should be always noted, so as to obtain knowledge

of the strength of the stimulus that is being used. There is no instrument that can be used for measuring the strength of the faradic current when testing, and the most that can be done is to make a preliminary trial in the way described, the operator testing the interossei of his own hand, duly moistened, placed in contact with the patient's limb.

The discovery of the motor points when testing is not the difficult task that it appears to be to the beginner after inspecting the plates after page 160. As already mentioned, he will soon remember where each one is to be found after some practice on his own muscles. It is a good plan also to study the pictures of the dissections of the muscles in a work on anatomy, so as to get a better idea of the position of the various parts.

The position of the motor points is shown in Plates I. to VI. These points have not always exactly the same position in different subjects, but the situation as shown in the plates represents the average of a large number of cases. The position where the nerve trunks are most accessible for electrical stimulation are shown in these plates.

How Electrical Testing is carried out.—The patient should recline on a couch on his back with head and shoulders raised. In this position the face, neck, arms, chest, abdomen and lower limbs may be tested. The back of the thigh and leg may be brought into view by flexion at the hip and raising them off the couch. For the back and shoulder muscles the patient should sit on the couch. For the gluteal muscles the patient must lie face downwards.

The indifferent electrode may be placed on the chest when the neck, shoulders, upper limbs and back have to be tested, or behind the hips when the front of the trunk and lower extremities are to be tested. When the

intrinsic muscles of the hands or feet are to be tested, it should be placed on the palms or soles. Frequently, the facial muscles only are to be tested : in this case the palm may be placed on the indifferent electrode. The skin in contact with this electrode should be well moistened with salt solution and the electrode itself, similarly soaked, should make good and even contact.

The part to be tested should now be moistened with salt solution. One hand of the operator, similarly moistened, should grasp the part ; the induction coil is started and the active electrode, also moistened with the same solution, placed on the back of the operator's hand over the first dorsal interosseous muscle. The key on the electrode should then be closed, so as to allow the current to flow and ascertain its strength. When strong enough to cause distinct contraction of the muscle mentioned, the electrode should be placed over the motor point of each muscle in turn that is to be tested, and the key depressed for a moment, so as to ascertain the response of each muscle. The position of the electrode should be adjusted so as to lie directly over the motor point, and when this has been done the most vigorous contraction will be produced.

When testing with the faradic current the following inquiries should be made :

(1) Is there any response of the muscles at all ? Be sure that the electrode is on the motor point and that it is making good contact, also the indifferent electrode.

(2) Is the response of the muscles much enfeebled ? In some cases the weakening will be quite apparent. In others it will be very difficult to decide whether the response is weaker than normal. There is no ready method of measuring the response, and, as already said, there is no way of measuring the strength of the faradic

current. Some information may be obtained by comparing the response given by the same muscle of the opposite side (if healthy) under the same conditions and with the same precautions ; small differences are very difficult to detect, but they are not of much importance for diagnosis.

(3) Is the response of the muscles much increased? Here again small increases are not of importance, and are difficult to diagnose with certainty.

After testing each muscle with the faradic current, repeat the test with the galvanic current. It is insufficient to bring the test to a close without using the galvanic current, unless the operator can say for certain that the contractions produced by the faradic current are not weakened, and it is sometimes difficult to be sure on this point. And it is incorrect to say that the reaction of a muscle is normal because it contracts in response to the faradic current. Muscles of which the reactions are certainly abnormal are frequently seen in which there is some response to the faradic current, or a response when this current is made stronger.

When using the galvanic current, make the testing electrode the kathode, and make a preliminary trial of the strength of the current, and when testing the patient's muscles use a current that is just strong enough to produce a distinct twitch of the muscle at the moment when the key is depressed and the circuit completed. Make the following inquiries :—

(1) Is the twitch smaller or larger than normal, or is it absent altogether? The same difficulties present themselves when trying to settle the question of the size of the twitch whether larger or smaller than normal. Small differences are unimportant. The reading of the milliampere-

meter gives some measure of the strength of the stimulus, but the actual number of the milliamperes required to produce a twitch will vary from patient to patient even if the muscles are normal. The number of milliamperes will also vary, slightly, from muscle to muscle; the farther the motor point beneath the skin, the stronger will be the stimulus necessary. But in making comparisons with the muscles of the opposite side (if they are normal) the reading of the milliampere-meter will indicate whether an equally strong stimulus is being used on both sides.

(2) Is the twitch quick like that customary for normal muscles, or is it slow and sluggish? Under certain circumstances (to be mentioned hereafter) the response of the muscle is quite different from that which is seen in health. Instead of the brisk twitch, there is slow, lazy shortening and relaxation of the muscle that sometimes looks like a peristaltic wave. When testing, therefore, with the galvanic current, it must be noted whether the response is a quick twitch or a sluggish contraction.

It will be noted that when the muscle makes this slow response, the current will often evoke a bigger contraction when the electrode is *off* the motor point, and that the biggest responses are obtained when the electrode is at the peripheral end of the muscle. Sometimes it will be found—and this is very important—that the muscle will give a quick twitch when the electrode is placed on its motor point, but a sluggish contraction when placed on the peripheral ends. It is therefore always advisable when in doubt whether the response to the galvanic current is

quick or slow, to stimulate the fleshy extremities of the muscle and inquire—

(3) Is the contraction produced by stimulating the peripheral end of the muscle slower than that produced by stimulating the motor point ?

Testing the Nerve Trunks.—After testing the muscles, proceed to test the main nerve trunks in which lie the motor supply. The testing electrode should be placed over the nerve trunk ; the indifferent electrode must be placed so that when the current flows none of the muscles that are supplied by the nerve will be traversed by it, and so possibly be stimulated to contract.

The nerve is tested first with the faradic current, and it should be noted whether the muscles respond or not. If any of them do not respond, the nerve is tested with the galvanic current, using the kathode as the testing electrode, and again it should be noted whether the muscles contract or not. If the paralysis is due to injury the nerve should be tested wherever possible above and below the site of the injury and in the region of the injury itself.

The points for stimulating the principal nerve trunks are shown in Plates I. to VI.

Types of Electrical Reaction of Muscle and Nerve.—(*a*) *Normal Type.*—When a muscle and its motor nerve are healthy it contracts when stimulated by the faradic current and remains contracted so long as the current flows. The same response is noted when its motor nerve trunk is stimulated. With the galvanic current a single quick twitch occurs at the moment the circuit is completed or closed. This twitch is known as the " closure contraction," and when the testing electrode is the kathode, it is called the " kathodic closure contraction," or, for short, KCC. A similar quick twitch occurs when

the galvanic current stimulus is applied to the nerve. These reactions are known as normal reactions.

When the test is being made and the muscle contracts strongly when the faradic current is used, it may be almost certainly said that its reactions are normal. But it is not always easy to be sure whether the contraction caused by the faradic current is of normal strength, especially as there is no method of measuring the strength of this current. It is always advisable when in doubt to use also the galvanic current, testing the muscle at its motor point and peripheral end where it joins its tendon. If the muscle is normal, it will contract quickly when stimulated at its motor point, and not at all when stimulated at its peripheral end—that is, if the current is not strong. If the current is strong, there may be a contraction when the peripheral end is stimulated, but it is always feebler than that seen when the motor point is stimulated.

(*b*) *Normal Type, but weakened* (*Weak Normal*).—In some cases it will be noted that the contraction produced by the faradic current is obviously weakened. When the galvanic current is used and the twitch is feebler than normal, but not slow, the reactions of the muscles are of the normal type, but weakened. The muscle is said to show " weak normal " reactions. It is necessary to be sure that the response to the galvanic current is quick. This is not always easy. The muscle should be tested at its peripheral end as well as at its motor point, as mentioned under (*a*).

Small diminutions of excitability are not easy to be quite sure of, owing to the difficulty in obtaining at all times exactly similar conditions in all parts of the circuit. The degree of moisture and thickness of the skin, the pressure of the electrode, and its position are all possible disturbing factors. Where the disease is unilateral the difference in the behaviour of the two sides is the best guide, but

even here a difficulty arises in the fact that the skin of a paralysed limb sometimes has a much higher resistance. Fortunately the lesser degrees of quantitative change have little or no diagnostic value.

(*c*) In some cases it may be noticed that there is absence of excitability to both faradic and galvanic currents.

(*a*), (*b*) and (*c*) are examples of *quantitative* changes in the reactions—differences in degree, not in kind.

(*d*) In many cases it is noticed that the muscle does not contract at all when stimulated by the faradic current, and gives a sluggish contraction in response to stimulation by the galvanic current. Such a muscle is said to show the "reaction of degeneration." The symbol RD is generally used as an abbreviation for reaction of degeneration. When the nerve is tested, it will be found in many cases to be inexcitable by either current. The muscle is then said to show the complete reaction of degeneration (CRD). Sometimes, however, the nerve will respond to both currents or only to the galvanic.

It is sometimes found that muscles showing RD will, when stimulated by the galvanic current, at the moment when the circuit is closed give a larger contraction when the testing electrode is the *anode* than when it is the *kathode*, whereas the reverse is true for normal muscles. It was formerly thought that this alteration in which the ACC is greater than the KCC occurred in all cases of RD. It is, however, by no means a constant feature, and it sometimes depends on the chance position of the testing electrode. This "polar reversal," as it is sometimes called, is no longer included as essential for the diagnosis of RD.

(*e*) In some cases it is found that the muscle will respond, though feebly, to the faradic current, but gives a sluggish response to the galvanic current. Such a muscle is said to show the "partial reaction of degenera-

tion" (PRD). The distinction between this reaction and the weak normal reaction depends, therefore, on the response to the galvanic current, whether slow or quick. It is often difficult to decide this point. As already mentioned under (*a*) and (*b*), the peripheral ends of the muscle should be tested, and if the contraction is larger or slower than when stimulated at its motor points, the reaction may be regarded as a reaction of degeneration.

The anodic closure contraction should also be obtained and compared with the kathodic closure contraction, and if it is larger it provides additional evidence in favour of the reaction of degeneration. But if the anodic closure contraction is smaller than the kathodic, it does not exclude the possibility of the reaction of degeneration.

When a muscle shows a stronger and slower contraction when it is stimulated at its tendinous end than when it is stimulated at its motor point, it is said to show the "longitudinal reaction." It is really part of the reaction of degeneration.

(*f*) In Thomsen's disease (Myotonia) it is found that when the muscles are tested with the faradic current the contraction persists for some seconds (sometimes as long as thirty seconds) after the current has been stopped. The same thing is noticed when the galvanic current is used ; instead of a momentary twitch there is a prolonged contraction which lasts while the current is flowing, and persists from five to thirty seconds after it has ceased. This reaction is known as the myotonic reaction. It is characteristic of Thomsen's disease.

When a muscle shows RD the contraction produced by the galvanic current is sometimes seen to persist while the current flows. Such a contraction is called "galvanotonus," or "duration tetanus," but it does not persist when the current ceases to flow. Duration tetanus is

sometimes seen in healthy muscles when the galvanic current is strong.

(*g*) In myasthenia gravis the muscles are very quickly fatigued and their responses rapidly get weaker during the process of testing, with either faradic or galvanic current. The excitability may even be lost, but it returns after rest. The reaction is known as the "myasthenic reaction."

(*h*) *Rich's Reaction.*—In this reaction a twitch is obtained (using the kathode as the testing electrode) at the moment when the circuit is opened and the current ceases to flow, with a current that is just strong enough to produce a KCC in a normal muscle. In normal muscles it requires a much stronger current to produce a KOC than a KCC.

The different reactions may be tabulated thus:

Reactions of Normal Type	Reactions of Abnormal Type
Normal. Weak Normal Reaction. Strong Normal Reaction. Rich's Reaction.	I. Reaction of Degeneration. (1) Partial. (2) Complete: (*a*) With loss of excitability of nerve to both currents. (*b*) With loss of excitability of nerve to faradic current, not to galvanic. (*c*) With no loss of excitability of nerve. II. Myotonic Reaction. III. Myasthenic Reaction.

Meaning of the Various Types of Electrical Reaction.—When a muscle shows the reaction of degeneration it indicates that there is a lesion somewhere in its motor neuron and localised to the *lower* neuron. There may be either injury or disease, and it may affect any part of the lower motor neuron, either the motor nerve cells of the anterior horn of the spinal cord (or in the case of a cranial nerve the cells of its motor nucleus) or the motor nerve

fibres or their end plates. If the lesion affects the upper motor neuron (*i.e.* the nerve track between the cerebral cortex and the anterior horn cells) the reaction of degeneration is not seen.

It further indicates that the lesion is of some degree of severity. Slighter degrees of injury or disease will produce simply quantitative alterations of the reaction—that is to say, the reaction will be of the normal type, but the contractions to both currents will be weaker.

When the reaction of degeneration is partial (*i.e.* when there is some survival of excitability to the faradic current) it may be taken to indicate that the lesion is less severe than when the reaction is complete. Direct stimulation of the nerve gives information on the condition of the latter. If the nerve retains its excitability to both currents and its conductivity (as shown by the contraction of the muscles when the nerve is stimulated), it is an indication that it is less severely damaged than when its excitability and conductivity are lost. In some cases the nerve loses its excitability to the faradic current, while retaining it to the galvanic current. This, probably, indicates a condition intermediate between those in which there is complete loss of excitability to both currents and the retention of excitability to both currents.

Weak normal reactions are found in milder cases of injury or disease of the lower motor neuron—cases which would, if more severe, show RD.

Increased normal reactions occur in cases of paralysis in which there is a lesion in the upper motor neuron. Vigorous reactions of the normal type are seen in tetany.

The myotonic and myasthenic reactions are characteristic of the diseases known as myotonia (Thomsen's disease) and myasthenia gravis.

Rich's reaction is supposed to occur in muscles paralysed as the result of pressure on the nerve trunk.

The motor nerve cells and their fibres do not solely

serve the purpose of conveying impulses causing contraction. The anterior horn cells exercise influence over the condition of the contractile substance of the muscle. When the motor nerve is permanently severed the muscles will gradually degenerate and ultimately be replaced by fibrous tissue, although it retains its blood supply and is made to contract artificially by electrical stimuli.

The behaviour of a muscle under electrical stimulation when the nerve has been sufficiently injured or diseased to show RD has been explained in the following way by Mlle Ioteyko. The muscle is supposed to contain contractile substance of two kinds: (1) a striated portion which contracts briskly and will respond to very brief as well as to slow stimuli ; (2) the undifferentiated sarcoplasm, which contract sluggishly and require long duration impulses to cause it to contract. When the nerve has been injured or diseased the striated portion degenerates or becomes functionless much more quickly than the sarcoplasm. Hence very brief stimuli, such as supplied by the induction coil, will not cause contraction, because the striated portion has passed out of use and the sarcoplasm is unable to respond to very brief stimuli. The sarcoplasm can, however, contract when stimulated by the slower impulse of the galvanic current and contract slowly, as is its custom, when the striated portion is not in action.

Course of the Reaction of Degeneration: its First Appearance.—The reaction of degeneration does not appear at the onset of disease or injury of the nerves, even when these have been completely divided. After complete division of its nerve the muscle ceases to respond to the faradic current in from four to seven days, while, according to Sherren, the sluggish response to stimulation with the galvanic current begins about the tenth

day. The actual time at which RD is fully developed probably varies in different cases, according to the exciting cause.

If the muscle has been completely and permanently cut off from the anterior horn cells, the reaction of degeneration persists, but becomes slowly and progressively feebler, and, after one year, it may be impossible to elicit any response to electrical stimulation.

In less severe injury, when the muscle has not been permanently cut off from the influence of the anterior horn cells, RD may persist for a longer time and, if recovery takes place, there may be no period during which there is no response to electrical stimuli.

RD may persist for several years. Lewis Jones believed that this persistence of RD indicated that there were still some representations of the muscle in the anterior horn of the spinal cord.

Prognosis of RD.—It must not be thought that a muscle with RD is irreparably damaged and that normal reactions cannot return. The recovery of normal reactions is a frequent occurrence, and it is often found that voluntary power returns and becomes fairly good before the RD has disappeared. The author has kept some cases showing RD under observation for considerable periods and has noted return of voluntary power nearly equal to that of the sound muscles on the opposite side, and recovery of the size of the affected limb *with persistence of RD.* In these cases the motor nerve had not lost its excitability.

In cases of injury to nerves the operator is asked to report on the electrical reactions of the muscles and give an opinion whether the nerve is divided or not. The question is often very difficult to answer. If the muscle shows RD that is *partial* it indicates that there is still physiological and anatomical connection between the

muscle and the spinal cord, and the outlook is favourable. If the RD is complete, but the nerve retains its excitability to one or the other current, the outlook is also favourable. If the RD is complete and the nerve inexcitable, then the prognosis is very uncertain and there is no electrical test that will show whether the injury that has separated the muscle from the influence of the anterior horn cells has either divided the nerve trunk completely (or severed the fibres within the sheath), or has bruised it sufficiently to separate the muscle from the influence of the anterior horn cells for a short time or a long time. If the excitability of the nerve to electrical stimulation has disappeared and that of the muscle has disappeared or is disappearing, the damage to the nerve has been sufficiently severe to call for surgical exploration.

Practical Difficulties in Testing.—When the operator has become familiar with the position of the motor points there will be little or no difficulty in testing when the reactions are normal or when the complete reaction of degeneration is present. The chief difficulty lies in the decision whether a muscle shows a weak normal reaction or a partial RD. The decision depends on whether the response to the galvanic current is quick or slow. In some cases the response is so slow that there is no difficulty in diagnosing the reaction as partial RD. In other cases it is very difficult to be sure whether the response is quick or slow. In these cases the tendinous end of the muscle should be tested with the galvanic current. If this is done and the response is *weaker* than that seen when the motor point is tested the muscle has probably a weak normal reaction. If, on the other hand, the response seen when the tendinous end is stimulated is certainly as large as, or larger than, that noted when the motor point is stimulated, and especially if it is slower, the muscle has most probably shown a partial RD.

It is often difficult to be sure whether a reaction is normal or weak normal. It is almost impossible to be sure of *small* differences in the amount of the response to electrical stimulation, but small differences are not of importance for the purpose of diagnosis. The method of testing by condenser discharges will be of help in this matter (see below).

Defects of the Method of Testing by Faradic and Galvanic Currents.—The method of testing by means of the galvanic and faradic currents has various defects. In the first place, the strength of the faradic current is not, in practice, measurable, while the duration of the separate impulses varies in different coils and is always longer than the shortest to which healthy muscle can respond, and often it is very much longer. A muscle will have passed out of the normal if it requires an impulse as long as that furnished by many induction coils before it will contract. It does not necessarily follow, therefore, that a muscle must be normal because it responds to the faradic current. On the other hand, although the strength of the galvanic current can be measured by the milliampere-meter, the time during which it is allowed to flow is not measured and is always too long.

Testing by Means of Condenser Discharges.—By this method the strength and duration of the impulses is measured. The apparatus consists of a box of condensers which vary in capacity between 0·01 microfarad and 2·00 microfarads. There are ten intermediate sizes. By means of a metronome any one of these condensers can be alternately charged to a known voltage from the main and then discharged through the patient. The duration of the discharge of a condenser depends, (1), on its capacity : the larger the capacity the longer the duration ; (2), on the resistance of the circuit along which

the condenser discharges. The chief resistance in the circuit is the body. For impulses of very short duration the resistance of the body is constant and may be taken as 1000 ohms in the condition under which the test is performed.

The smallest condenser in the box would then give an impulse lasting only $\frac{1}{24,000}$th of a second, the largest condenser $\frac{1}{200}$ of a second. The voltage to which they are charged can be varied ; usually it is 100.

To carry out a test the muscles are tested successively with the condensers, beginning with that of the smallest capacity and proceeding till one is found to which the muscles will just respond. The capacity of this condenser or the duration of its discharge through the body gives the measure of the condition of the muscle. There is no need to decide whether the contraction is quick or slow.

It may be taken that muscles with reactions of the normal type will require condensers of capacities measured in hundredths of a microfarad (0·01 to 0·09), according to the degree of departure from the normal ; muscles with a partial RD require condensers measured in tenths of a microfarad (0·10 to 0·90) ; muscles with complete RD require condensers of one or more microfarads.

Instead, therefore, of three types of reaction—normal, partial RD and complete RD—we have twelve degrees of departure from normal, each being represented numerically.

After the new apparatus had been used for testing it was soon found that many muscles showing RD could not respond even to the largest condenser (2·00 microfarads). This condenser does not provide an impulse long enough for most cases of RD. Bigger condensers cannot be used, because when charged to 100 volts their discharge gives too great a shock. The difficulty may be surmounted

by enclosing an additional resistance in series with the patient. This has the effect of lengthening the duration of the discharge. Thus by using a resistance of 5000 ohms the discharge of the condensers through the body can be increased sixfold. It is thus possible to increase the duration of discharge of the 2·00 microfarads condenser to $\frac{1}{30}$th of a second. Another way of overcoming the difficulty is to use condensers larger than 3·00 microfarads, but charge them to a lower voltage, say 50. Muscles with RD sometimes will respond to discharges at lower voltage than will normal muscles.

It was further found that muscles showing partial RD varied greatly with regard to the capacity of the condenser required to make them contract. Some required large condensers (tenths of a microfarad), but many others would respond to much smaller condensers. There are thus many varieties of partial RD.

The testing of the reactions of muscle and nerve by condenser discharges has the following advantages. The method is more accurate because we are using *measured* stimuli, their duration varying between the shortest to which normal muscle and nerve will respond and the longest required for the same tissues when in a condition of degeneration. In the older method we use only two stimuli, the faradic and galvanic currents, the duration of both of which are unmeasured, the former being not short enough, the latter too long. The new method yields more information. The degree of deviation from the normal can be expressed accurately, in terms of the length of the discharge that is just able to provoke a response from the muscle or nerve. A test made by the condenser method causes much less pain than that produced by the galvanic current, and it takes less time.

PLATE I

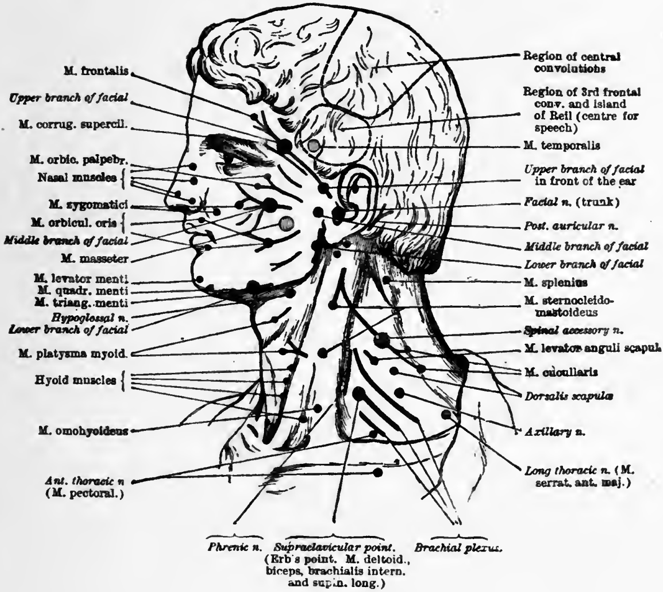

M. frontalis
Upper branch of facial
M. corrug. supercil.
M. orbic. palpebr.
Nasal muscles
M. zygomatici
M. orbicul. oris
Middle branch of facial
M. masseter
M. levator menti
M. quadr. menti
M. triang. menti
Hypoglossal n.
Lower branch of facial
M. platysma myoid.
Hyoid muscles
M. omohyoideus
Ant. thoracic n
(M. pectoral.)
Region of central convolutions
Region of 3rd frontal conv. and island of Reil (centre for speech)
M. temporalis
Upper branch of facial in front of the ear
Facial n. (trunk)
Post. auricular n.
Middle branch of facial
Lower branch of facial
M. splenius
M. sternocleido-mastoideus
Spinal accessory n.
M. levator anguli scapul.
M. cucullaris
Dorsalis scapulæ
Axillary n.
Long thoracic n. (M. serrat. ant. maj.)
Phrenic n.
Supraclavicular point.
(Erb's point. M. deltoid., biceps, brachialis intern. and supin. long.)
Brachial plexus.

PLATE II

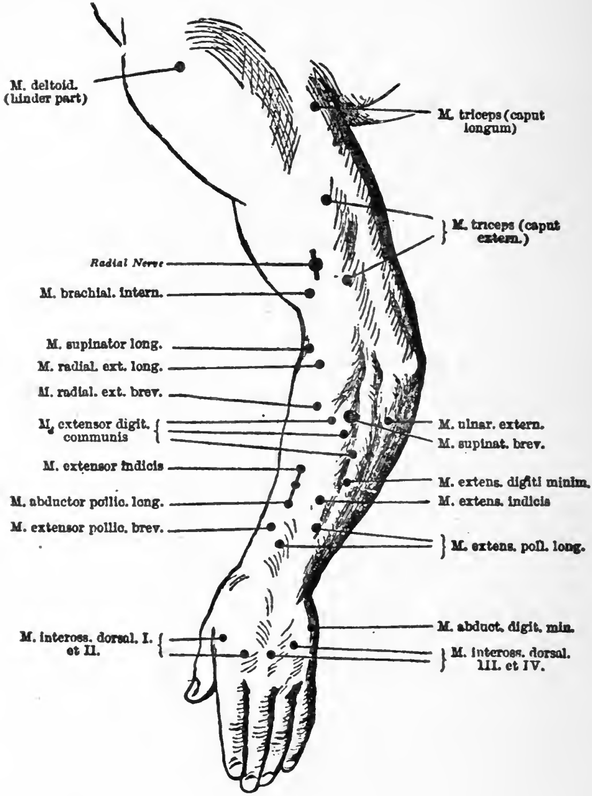

M. deltoid. (hinder part)
M. triceps (caput longum)
M. triceps (caput extern.)
Radial Nerve
M. brachial. intern.
M. supinator long.
M. radial. ext. long.
M. radial. ext. brev.
M. extensor digit. communis
M. ulnar. extern.
M. supinat. brev.
M. extensor indicis
M. extens. digiti minim.
M. abductor pollic. long.
M. extens. indicis
M. extensor pollic. brev.
M. extens. poll. long.
M. abduct. digit. min.
M. inteross. dorsal. I. et II.
M. inteross. dorsal. III. et IV.

PLATE III

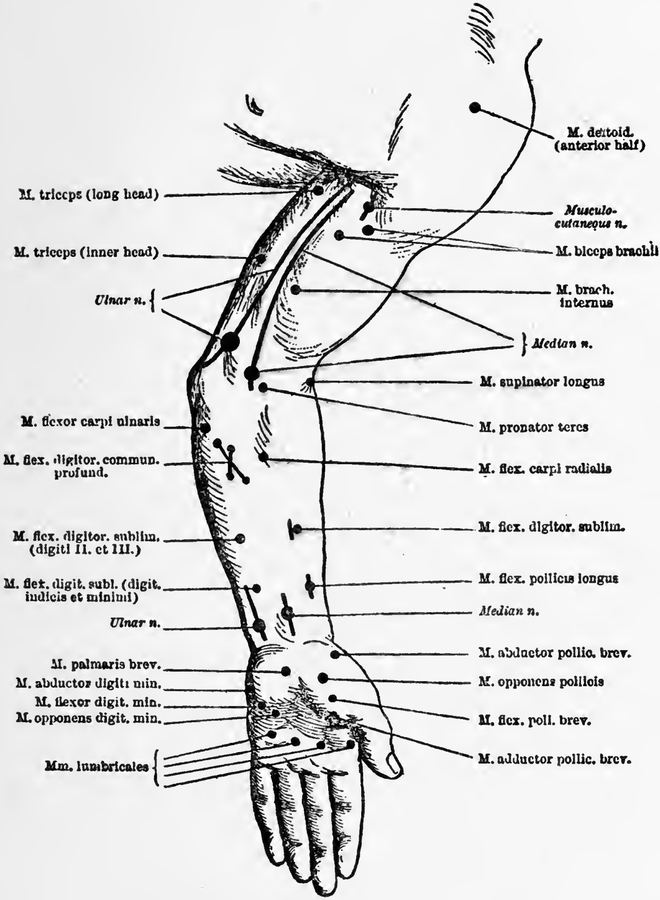
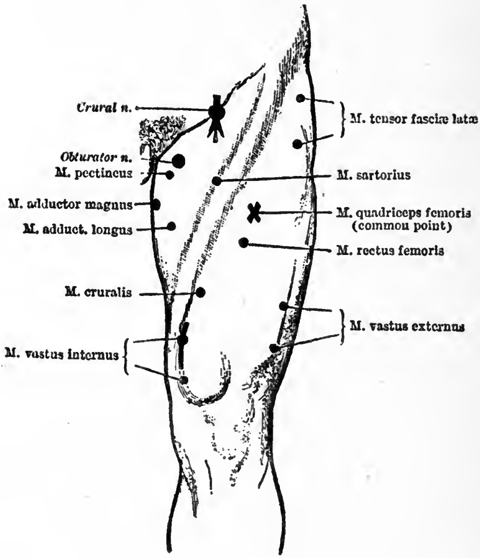

M. deltoid. (anterior half)
M. triceps (long head)
Musculo-cutaneous n.
M. biceps brachii
M. triceps (inner head)
Ulnar n.
M. brach. internus
Median n.
M. supinator longus
M. pronator teres
M. flexor carpi ulnaris
M. flex. digitor. commun. profund.
M. flex. carpi radialis
M. flex. digitor. sublim.
M. flex. digitor. sublim. (digiti II. et III.)
M. flex. pollicis longus
M. flex. digit. subl. (digit. indicis et minimi)
Median n.
Ulnar n.
M. abductor pollic. brev.
M. palmaris brev.
M. abductor digiti min.
M. opponens pollicis
M. flexor digit. min.
M. opponens digit. min.
M. flex. poll. brev.
Mm. lumbricales
M. adductor pollic. brev.

PLATE IV



Crural n.
Obturator n.
M. pectineus
M. adductor magnus
M. adduct. longus
M. cruralis
M. vastus internus
M. tensor fasciæ latæ
M. sartorius
M. quadriceps femoris
(common point)
M. rectus femoris
M. vastus externus

PLATE V

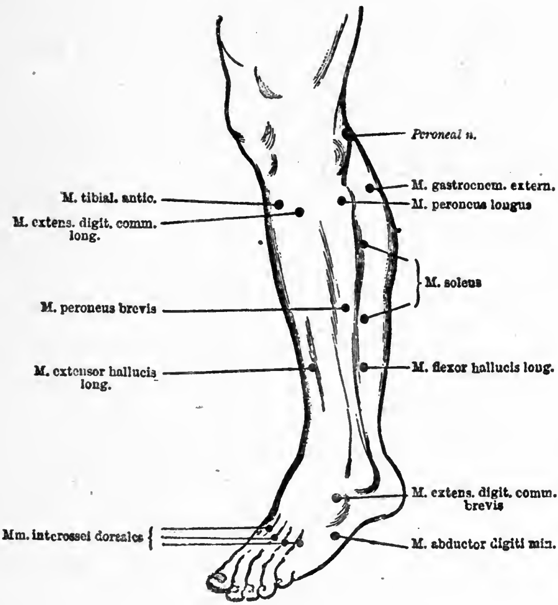

Peroneal n.
M. gastrocnem. extern.
M. peroneus longus
M. tibial. antic.
M. extens. digit. comm. long.
M. soleus
M. peroneus brevis
M. extensor hallucis long.
M. flexor hallucis long.
M. extens. digit. comm. brevis
Mm. interossei dorsales
M. abductor digiti min.

PLATE VI

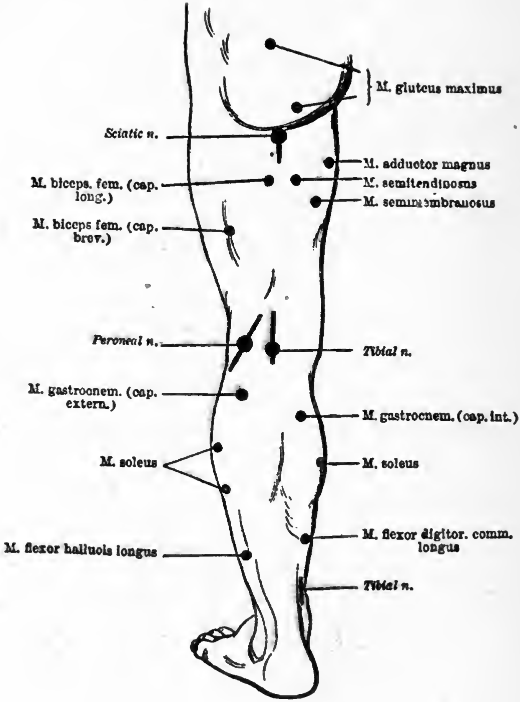

M. gluteus maximus
Sciatic n.
M. adductor magnus
M. biceps. fem. (cap. long.)
M. semitendinosus
M. semimembranosus
M. biceps fem. (cap. brev.)
Peroneal n.
Tibial n.
M. gastrocnem. (cap. extern.)
M. gastrocnem. (cap. int.)
M. soleus
M. soleus
M. flexor digitor. comm. longus
M. flexor hallucis longus
Tibial n.

PLATE VII

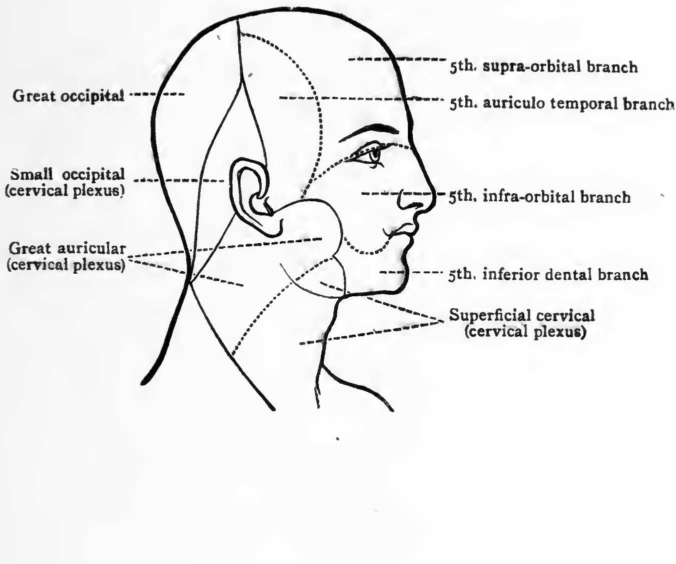
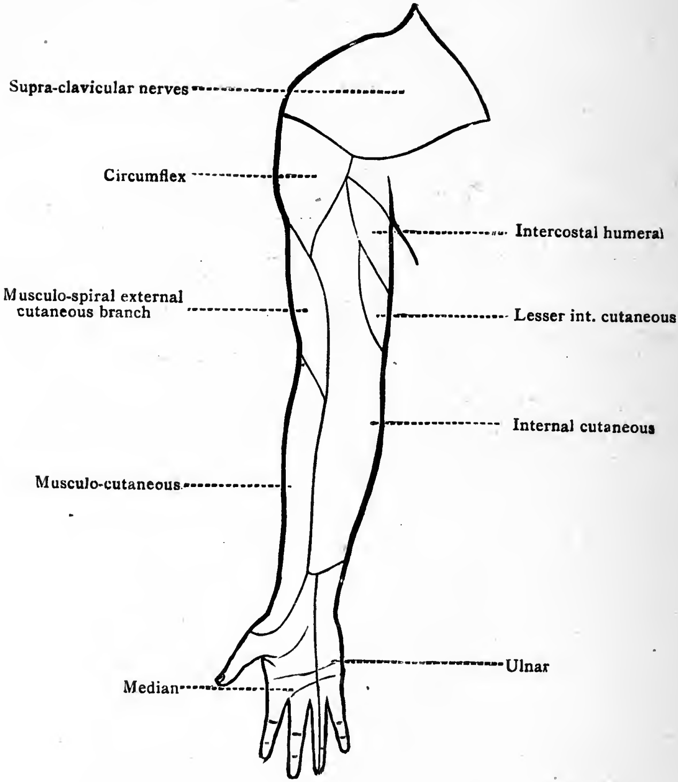
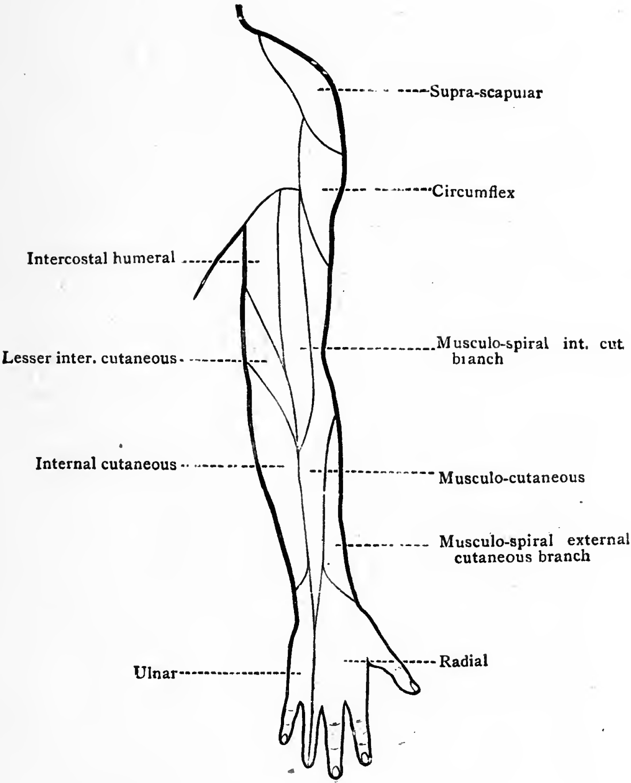

Great occipital
Small occipital (cervical plexus)
Great auricular (cervical plexus)
5th. supra-orbital branch
5th. auriculo temporal branch
5th. infra-orbital branch
5th. inferior dental branch
Superficial cervical (cervical plexus)

PLATE VIII.



Supra-clavicular nerves
Circumflex
Intercostal humeral
Musculo-spiral external cutaneous branch
Lesser int. cutaneous
Internal cutaneous
Musculo-cutaneous
Ulnar
Median

PLATE IX



Supra-scapuiar
Circumflex
Intercostal humeral
Musculo-spiral int. cut branch
Lesser inter. cutaneous
Internal cutaneous
Musculo-cutaneous
Musculo-spiral external cutaneous branch
Radial
Ulnar

PLATE X

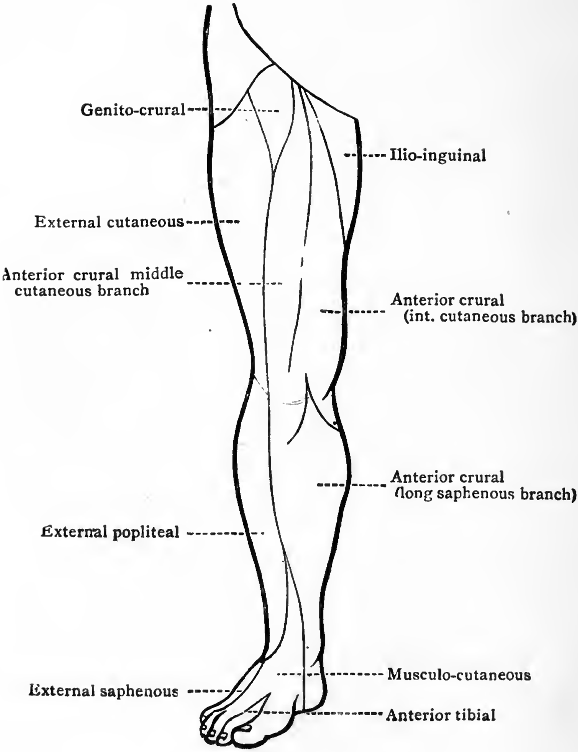
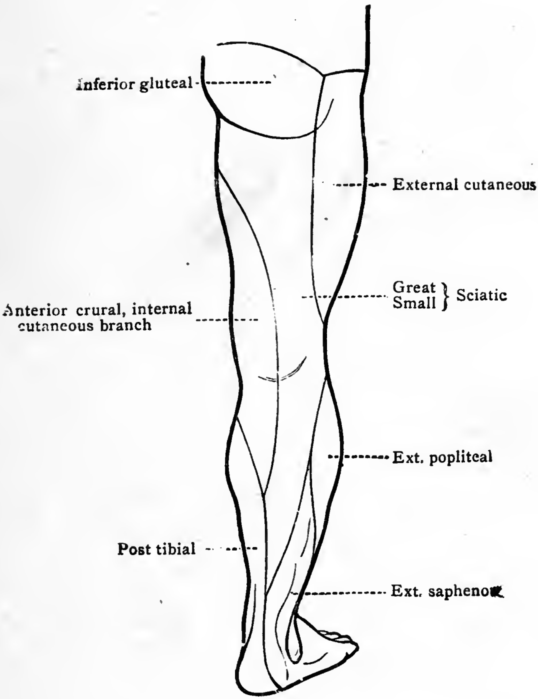

Genito-crural
Ilio-inguinal
External cutaneous
Anterior crural middle cutaneous branch
Anterior crural (int. cutaneous branch)
Anterior crural (long saphenous branch)
External popliteal
Musculo-cutaneous
External saphenous
Anterior tibial

PLATE XI


Inferior gluteal
External cutaneous
Great
Small
Sciatic
Anterior crural, internal cutaneous branch
Ext. popliteal
Post tibial
Ext. saphenous

CHAPTER XI

HIGH-FREQUENCY CURRENTS

A HIGH-FREQUENCY current is one that periodically reverses the direction of its flow at an exceedingly high rate. A current may be made to reverse its direction any number of times per second, but when the frequency of reversal is sufficiently high the physical properties of the current and its action on living tissues are profoundly altered. The current is no longer able to produce chemical (electrolytic) changes in solutions of salts, nor is it able to evoke a response from the excitable tissues. The frequency of reversal may be called *high* when the current is unable to produce these chemical changes or to stimulate muscle and nerve to give their customary response. Such a frequency would be about a million times a second.

How High-Frequency Currents are produced.—A continuous current may be made to reverse its direction periodically by means of a simple apparatus known as a current reverser or commutator. No mechanical apparatus of this kind can produce a sufficiently high frequency of reversal, and the current is generated on quite a different principle.

If a condenser, such as a Leyden jar, is charged and then discharged, the current that flows during the period of the discharge, though of momentary duration, will be a high-frequency current if certain requirements are fulfilled in the circuit along which the discharge takes place. The resistance of the circuit must not exceed a

certain value. In the second place, the circuit must be arranged so that self-induction (page 287) can take place along it. Both these requirements will be satisfied if the circuit is constructed of a thick copper wire bent in the form of a spiral. If the discharge takes place along

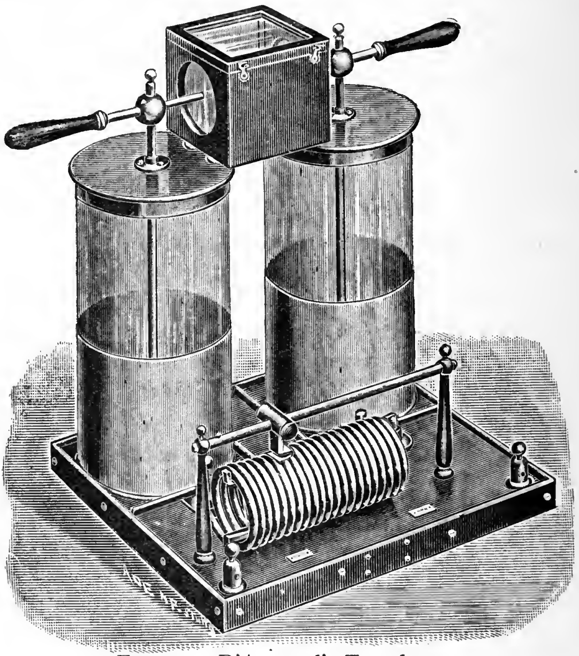


FIG. 44.—D'Arsonval's Transformer

such a circuit, the current that traverses it will flow or oscillate backwards and forwards from one coat of the condenser to the other, getting successively feebler with each reversal till it dies away. At this moment the condenser is discharged. All this takes place in a very brief period of time, its duration depending on the capacity of the condenser, and the resistance of the circuit and the

amount of self-induction that takes place in the circuit. If these factors are known the number of oscillations per second (*i.e.* the "height" of the frequency) can be calculated.

Apparatus for the Production of High-Frequency Currents.—The arrangement of Leyden jars and wire

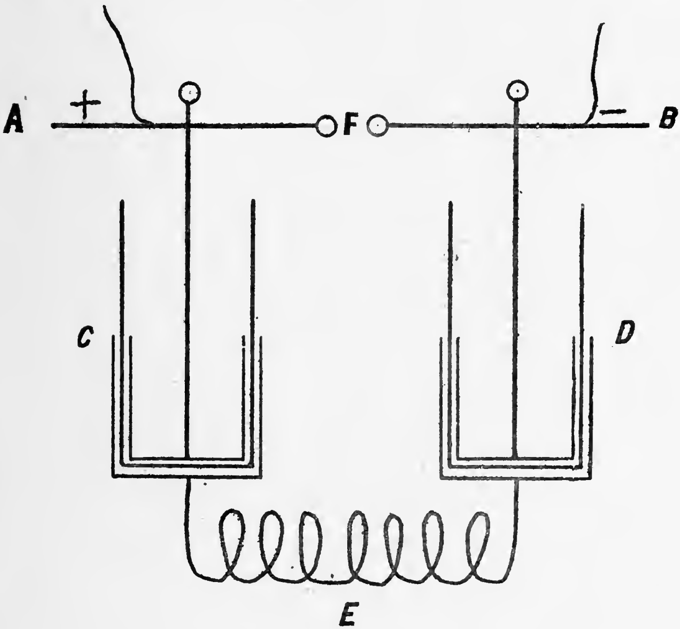


FIG. 45.—Plan of High-Frequency Arrangement

spiral is shown in Fig. 44, and the plan is shown in Fig. 45 and is known as a d'Arsonval transformer. It is named after Prof. d'Arsonval, of Paris, the pioneer worker in high-frequency currents in their physiological and medical application. It is a simple device for converting or transforming continuous currents or

alternating currents of low frequency into others of high frequency. In Fig. 45, *C* and *D* represent the condensers (Leyden jars) in section, each with its outer and inner coat and the intervening insulating material (glass). The inner coatings are connecting to the terminals of an induction coil. The outer coats are connected by the wire spiral, *E*. This spiral is made of twenty turns of thick copper wire. It is known as the "solenoid." Sometimes a movable handle is fitted so that the number of coils included between the outer coatings of the jars may be varied.

Sliding rods with a ball at one end and an ebonite handle at the other are attached, one to each metal pillar that makes contact with the inner coating of each jar. The space between the balls is the "spark-gap," and it can be varied by sliding the rods to or from each other.

The jars may be charged from a static electrical machine, or from an induction coil. The usual source is a large induction coil of the type used for X-ray work. When the induction coil is used we are really deriving our supply from a constant current (taken from the mains or a battery), and the induction coil serves to transform this current, raising its voltage to the necessary degree. The alternating current from the mains may also be used to charge the jars after its voltage has been raised suitably by a static transformer. When the induction coil is set in action and the spark-gap sufficiently narrowed a torrent of noisy sparks darts across the gap, and at the same time the solenoid is traversed by high-frequency currents. The following events take place. The inner coats of the jars are charged, one positively, the other negatively. Charges of opposite sign are induced on the outer coats. The charges on the inner coats neutralise each other by sparking across the gap and simultaneously the induced charges on the outer coats neutralise each other and a momentary current passes along the solenoid.

This current is a high-frequency current, because the solenoid has a low resistance and allows sufficient self-induction to take place.

The sparks that appear at the gap seem to follow each other without intermission, and hence it would appear that the charging and discharging of the jars are continuous, giving rise to sustained high-frequency currents along the solenoid. This, however, is not the case. The jars are charged only at the moment when the " break " current is induced in the secondary wire of the coil. They are therefore charged not continuously but intermittently, the actual number of times per second depending on the

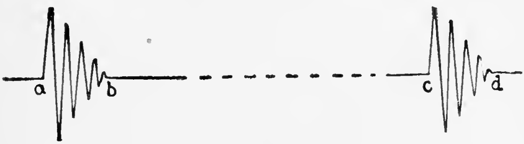


FIG. 46.—Intermittent Trains of Oscillations
a to b—Train of oscillations, lasting $\frac{1}{50,000}$ sec.
b to c—Intermission, lasting $\frac{1}{100}$ sec.
c to d—Next train of oscillations

rate at which the interrupter makes and breaks the current supplied to the coil. Suppose that this rate is 100 per second. Each $\frac{1}{100}$th of a second the jars are charged and discharged, giving rise to a high-frequency current in the solenoid. But the jars take a much shorter time than $\frac{1}{100}$th of a second to completely discharge. It may be taken, for jars of the capacity used in the d'Arsonval transformer, as $\frac{1}{50,000}$th of a second. It follows that every $\frac{1}{100}$th of a second a train of high-frequency oscillations lasting $\frac{1}{50,000}$ traverses the solenoid. The high-frequency current as supplied by the d'Arsonval transformer is, therefore, intermittent, short trains of oscillations separated from one another by very much longer intervals of rest. It may be represented as shown in Fig. 46.

Although the actual resistance of the solenoid to a direct current is extremely low, its resistance to the high-frequency current is very great, even though the potential difference between the outer coats of the Leyden jars is very high, amounting to many thousands of volts. This is because the wire of the solenoid is bent in the form of a spiral with closely adjacent coils so that other currents are induced in the same circuit. It will be remembered that the moment a current begins to flow along a spiral, another current is induced in the same circuit and flows in the opposite direction and impedes it. The induced current is only of momentary duration, so that its only effect on the other current is to impede it at its commencement and so retard its rate of growth to its maximum. But if the inducing current lasts only for the same brief period as the self-induced current it will be opposed considerably and prevented from growing to its full strength. The high-frequency current flows only for a moment in one direction before it reverses, and it is therefore greatly opposed by the currents it induces in its own circuit. If a straight wire connects the ends of the solenoid the high-frequency current will travel by preference along the former, even if it has to spark across a small air-gap in the circuit, and so overcome a high resistance. If the high-frequency current is to be applied to the body it is led off from the terminations of the solenoid by means of suitably insulated cables.

FIG. 47.—Hot-wire Milliampere-meter

Measurement of High-Frequency Currents.—Alternating currents, whether of high or low frequency, cannot be measured by the ampere-meter described later (page 283), because their direction is constantly reversing. The hot-wire ampere-meter may, however, be used for the purpose (Fig. 47). In this instrument the current is led through a fine wire, of high resistance. The wire is heated in proportion to the strength of the current, so that it lengthens to a corresponding degree. The degree of lengthening is indicated by a needle moving over a scale calibrated so that a certain number of divisions correspond to a known current passing along the wire.

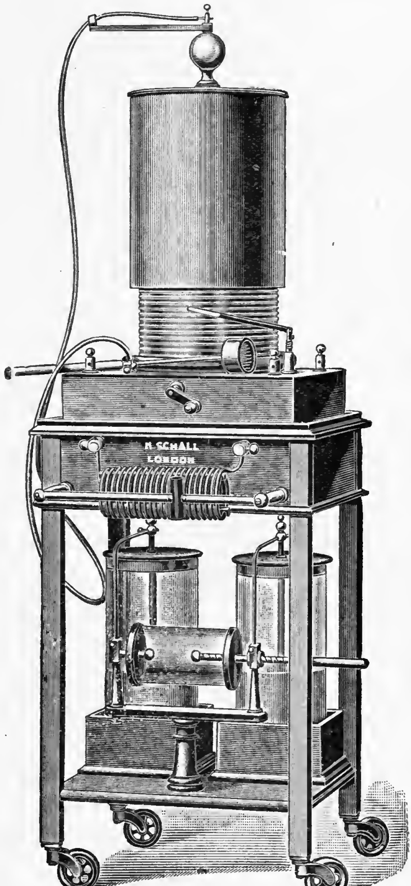


FIG. 48.—High-frequency Outfit

The current supplied by the d'Arsonval apparatus may reach a strength of 0·5 or 0·6 amperes (500 or 600 milliamperes) when traversing the body.

A complete form of high-frequency apparatus is shown in Fig. 48. The various parts are mounted on a trolley. The Leyden jars are on the lower shelf ; in front of them is the spark-gap, enclosed in a glass cylinder to diminish the noise of the sparks. Above the jars is the solenoid. On the top of the trolley is the "resonator" (see later, page 170).

How High-Frequency Currents are applied to the Body.—(1) *The Direct Method.*—The extremities of the solenoid are connected to electrodes placed in *direct* contact with the skin. The electrodes are made of sheets of pliable metal, such as copper, lead or tin cut to suitable sizes. They are placed in contact with the previously moistened skin and secured in position by a bandage or sand-bag. The metal should make even contact all over. Instead of placing the metal in direct contact with the skin, a pad of absorbent material, such as lint, soaked in salt solution may be interposed. Its thickness should be that of eight layers of lint, and its area should be slightly larger than that of the metal plate. It is soaked in a solution of salt so as to enable it to conduct the current readily. The strength of the solution should not be less than 5%. The metal plates are connected to the extremities of the solenoid by thickly insulated cables. Of the electrodes, one is the *active* electrode and is placed on the part to be treated. The other is the indifferent electrode. It is of larger size than the active electrode and is placed on some convenient part, preferably on the opposite aspect of the body. A second active electrode may be used instead of the indifferent electrode and both placed on the part requiring treatment, one on one side, one on the other.

(2) *Indirect Method.*—Instead of placing the indifferent electrode in direct contact with the body it may be placed a little distance away with the intervening space occupied

by some insulating material. Such an arrangement is seen in the "condenser couch" or "auto-condensation couch" (Fig. 49). This couch contains a long metal plate fixed under the upholstery and insulated from it. It is connected to one extremity of the solenoid. The patient lies on the upholstery, and the other end of the solenoid is attached to a metal handle, fixed to the couch and grasped by the patient, or to an electrode placed on any desired portion of the skin. The couch is called a "condenser couch,"

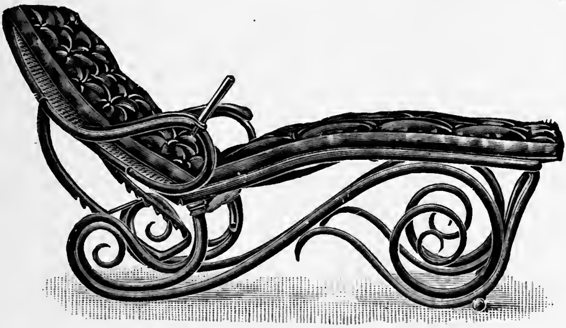


FIG. 49.—Auto-Condensation Couch

because the patient and the metal plate form the armatures of the condenser and the intervening insulating material the dielectric (see page 261 for description of condensers). The patient and the metal plate are alternately charged and discharged with a frequency corresponding to that of the oscillation of the current. The current surges to and fro and into and out of the patient, so that the whole body is brought under the influence of the current, and thus receives *general* treatment, while that part of the body in contact with the electrode receives the greatest concentration of the current, and so gets *local* treatment.

The condenser couch method, or "auto-condensation"

method as it is sometimes called, therefore enables both general and local applications to be made, while the metal electrode under the couch obviates the necessity of fixing an indifferent electrode in contact with the skin each time the treatment is given.

Another way of giving general applications of high frequency is to enclose the patient within a greatly enlarged solenoid. The patient stands or sits within the solenoid, the long axis of which is vertical. He does not come in contact with any part of it. His body is traversed by "eddy" currents that are induced within from the coils of the solenoid. This method of application is known as the "auto-conduction" method.

There is a method of applying high frequency specially suitable for local applications. If one of the electrodes attached to one end of the solenoid is placed in contact with the body and the other (the active) electrode be brought near to the skin without actual contact, a discharge of sparks will take place across the intervening space. If the active electrode terminates in a metal point or group of points, the discharge takes the form of a brush of very fine sparks or "effluve." To procure an efficient effluve it is necessary to have a considerably higher voltage between electrode and skin than that reached between the extremities of the solenoid. By connecting to one end of the solenoid an additional coil of wire, and attaching the active electrode to the free extremity of this coil, the voltage will be considerably raised. This additional coil is known as "Oudin's resonator." It is shown in Fig. 48, where it is seen mounted vertically on the top of the trolley, partly enclosed in an insulating cover.

It consists of a wooden cylinder or cage about nine inches in diameter, and fifteen to eighteen inches high, and wound with about sixty turns of moderately coarse wire—the individual turns are about one quarter of an

inch apart and should be evenly spaced at all points. The lower end of this wire is joined to some part of the thick wire spiral (solenoid) of the high-frequency apparatus, the best point being found by experiment. The upper end of the resonator terminates in a knob mounted on top of the instrument. The wire of the resonator acts as a continuation of the solenoid. It is possible to dispense with the latter and use the lower few turns of the resonator in its stead. If this is done, the lower (proximal) end would be connected to the outer coating of one jar, while the outer coating of the other is attached to a point a little higher up, changing it about until the best effect is produced. To the upper (distal) end of the resonator is attached an insulated cable and to the free end of the latter is secured the electrode. When the apparatus is set in action a profuse "brush discharge" or effluve is given off from the electrode. This effect is increased when one end of the solenoid—or, when this is not used, the lower end of the resonator winding—is connected to earth, by attaching it to a gas or water pipe. The length of the effluve depends upon the point along the spiral to which the outer coat of the second Leyden jar is connected, and a slight alteration in the position of this point may considerably increase the length of the effluve.

For local applications, many forms of electrodes have been used. The simplest is what is called the brush electrode, and consists of a metal plate from one to three inches in diameter and studded on one side with a number of sharp metallic points or tufts of fine brass wires or tinsel: to this metal plate is attached an ebonite rod for the operator to hold.

Other forms are made of closed glass tubes, either filled with some conducting liquid as water or saline solution, or exhausted until the partial vacuum produced becomes sufficiently conducting. They are sometimes

called condenser electrodes, because the internal conducting medium induces, when charged from the resonator, corresponding charges on the outside of the glass.

The most generally used condenser electrodes are the so-called "vacuum" electrodes (Fig. 50). These are closed glass vessels of various shapes and sizes, from which the air has been sufficiently exhausted to render the residual gas as good a conductor as possible. One end of the tube is pierced by a platinum wire fused into its wall. To this wire is attached the cable from the

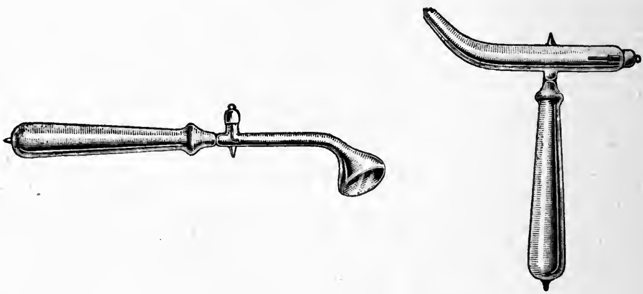


FIG. 50.—Vacuum Electrodes

resonator or solenoid. The other end of the tube is applied to the patient. When the current is turned on the air within the tube conducts the current and becomes incandescent, glowing with a violet-blue light. At the same time fine crackling sparks pass from the glass at the end in contact with the skin. The sparks are longer if the electrode is attached to the resonator than if it is attached to the end of the solenoid.

Of all the ways of applying high-frequency currents, the local application of the current from the top of the resonator is perhaps the most successful. It may be applied in the form of a soft brush discharge from a multiple point electrode held just so far from the patient that actual sparks do not pass. There is a copious

production of ozone and the brush itself acts as a mild stimulant. Instead of this we may use a vacuum electrode which is of glass and placed in contact with the surface to be treated. The strength of the application can be very gradually adjusted, and, speaking generally, it is more stimulating than the brush.

In some of these electrodes the vacuum is so high that X-rays are given off in small amount, but it is doubtful if such rays exist in sufficient quantity to have any effect.

The application from a vacuum electrode can be made so strong as to be decidedly painful and produce blistering if kept on too long. If such vigorous treatment as this is required it is better to use a plain metal point electrode, owing to the fact that the glass electrodes tend to become pierced under such conditions, and so rendered useless.

In use the metal point is held a little way off the surface to be treated, so that the spark has to jump across a gap the length of which is limited by the strength of the current employed. The rule is, the farther the point from the skin the more severe and painful is the effect.

If the point is held very close and a strong current turned on, the local effect seems to be to a great extent a thermal one and a small blister quickly forms—as we withdraw the point the character of the discharge changes, becoming more intermittent, more painful and disturbing to the patient, and the effect seems to influence the tissues some distance down—superficial muscles are thrown into contraction and the skin takes a "goose skin" appearance—later on the part becomes red and blisters form.

This method can be carried out by any high-frequency arrangement and will be found very useful in the treatment of warts, acne vulgaris, and port wine marks.

The Action of High-Frequency Currents on the Body.—High-frequency currents produce none of the sensations that are customarily associated with the passage of electrical currents. Although the high-frequency current may reach a magnitude of 500 milliamperes or more, there is no contraction of muscle, no perception of pain or tingling. The only sensation that is apparent is warmth, and this is, as a rule, slight and not immediately perceived.

We have now a satisfactory explanation of this apparently anomalous behaviour of electrical currents when they oscillate at an extremely high rate, and the matter has been considered in Chapter I., dealing with the mode of action of electricity on the body. It may be mentioned here that it is the movement of ions caused by the current that constitutes the electric stimulus and that the high-frequency current oscillates to and fro at a rate so high that the ions are unable to keep pace with it. There is therefore no movement imparted to them by the current, so that the latter is unable to stimulate the tissues. High-frequency currents can, however, bring about physiological and therapeutic effects, and the question arises, "What is the mode of action of these currents in bringing about the effects observed ?" Most probably by the production of heat. There is an actual sensation of heat in the skin, and it may be measured by a surface thermometer. The heat becomes greater as the area of contact between the electrode becomes smaller, thereby increasing the density or "concentration" of the current at its entry, and it may actually cause a burn if the electrode has the form of a wire or needle. The development of heat within a conductor by an electric current in proportion to the resistance of the conductor and the square of the strength of the current is a well-known physical law (Joule's law). In the case of high-frequency currents and the body, we have a

conductor of sufficiently high resistance and a current of sufficient strength, and when the current traverses the tissues heat is developed along its path, both on and within them. The development of heat *on* the tissues, "epithermy," can be readily demonstrated. The development of heat *through* the tissues, "diathermy," is less easy to demonstrate, as the currents produced by the commonly used d'Arsonval type of high-frequency machine are not very strong, and its density diminishes as it penetrates the tissues. But it is a necessary consequence of Joule's law that heat should be developed *within* the tissues as well, and it can be shown when stronger high-frequency currents (as generated by the diathermy apparatus described in the next chapter) are used.

High-frequency currents have for the past twenty years been used empirically, with varying degrees of success for many maladies. When this form of electrical treatment is to be applied, its mode of action by the production of heat on and within the tissues should be borne in mind, and the question of the advisability of its application and of the likelihood of benefit resulting should be considered from the same point of view.

High-frequency currents have the effect, when the whole body is brought under their influence, of increasing the metabolic changes. D'Arsonval showed that there was an increase in the output of carbon dioxide, of nitrogen and phosphates in the urine, and an increased output of heat. This is what might be expected to follow a gentle warming of the tissues. High-frequency currents have an influence on the vascular system. Sloan found that their first action was to produce a peripheral vaso-dilatation. The heart then beat more rapidly and counteracted the tendency to fall of blood pressure produced by the vaso-dilatation.

When local applications are made with the vacuum electrodes, no sensation other than that of heat is produced, if the glass is in contact with the skin ; when it is placed a short distance away, numbers of sparks leap across and produce a pricking sensation. The skin soon acquires a vivid erythema, and if the application is for more than a short time in one situation localised burning may result, especially if the current is strong. The application of the effluve produces the feeling of a warm breeze, which may become uncomfortably hot when the electrode is placed near to the body: if brought very close, sparks will pass and cause pain. The effluve also produces an erythema of the skin. The stimulation of the skin and the erythema are the result of heating of minute points on which the effluve or sparks fall. There is at the same time a production of ozone and oxides of nitrogen from the atmospheric gases. These gases penetrate for a short distance into the outer skin layer, or they may possibly be formed there. Their odour is perceived for a considerable time afterwards.

The therapeutic action of this local application of high frequency is probably the result of local heating and the resulting hyperæmia. Possibly the new gases formed may have some action, particularly when the treatment is applied to infected ulcers and to cutaneous affections, such as acne and sycosis and others.

High-Frequency and Surgical Cases.—It has been mentioned that the high-frequency sparks may produce destruction of the skin. They are actually used for the destruction of abnormal tissue. Metallic electrodes are used and sparks are directed from them on to the part to be treated. The destruction is brought about by the heat at the points on which the sparks fall. The tissue to be destroyed must be superficial and must not extend deeply. This form of treatment has been used with

success for flat nævi, moles and warts, and it has proved successful in some cases of lupus and rodent ulcers. Malignant growths have also been treated by long high-frequency sparks from powerful apparatus ; the name of " fulguration " has been given to such treatment.

CHAPTER XII

DIATHERMY

In the preceding chapter it was pointed out that the high-frequency current provided by the d'Arsonval type of apparatus was intermittent—that is to say, the oscillations occurred in groups, each separated from the preceding one by a long interval during which there was no current. It was shown that the time occupied by each group of oscillations was very short, while the interval between each group was relatively very long, so that during any period of treatment the body was under the influence of the high frequency for only a very short fraction of the time.

During recent years new types of apparatus have been designed for the purpose of producing high-frequency oscillations that are *continuously* kept up and not intermittent. With a current of continuous high-frequency oscillation the sensation of heat which, with the intermittent oscillations was slight or even imperceptible, becomes very pronounced and may be unbearable. The heat is developed along the path of the current, both in the superficial and deep parts. In recognition of this production of heat through the tissues as the essential action of sustained high-frequency currents on the body the word "diathermy" has been devised to describe this mode of electrical treatment. It may be said that all high-frequency currents produce some degree of diathermy, although the heat may not be perceptible or measurable. "High-frequency" treatment, as generally understood, refers to treatment by the intermittent

high-frequency current produced by the d'Arsonval type of apparatus, and the term "diathermy" is reserved for treatment by continuous high-frequency oscillations producing heat as the most conspicuous effect. Whether the high-frequency currents are intermittent, producing a trifling amount of heat, or continuous, producing a large amount, the therapeutic action, in both cases, is due to the same effect—viz. the production of heat on and within the tissues.

Diathermy has also been called "thermo-penetration" and "transthermy," terms which also express the result of the action of sustained high-frequency currents of sufficient intensity.

The Production of Continuous High-Frequency Currents.—These currents are generated on the same principle as the intermittent high-frequency current, but the various parts of the apparatus are modified. Instead of Leyden jars, the condensers are made of several sheets of metal separated and insulated from each other by glass or paper soaked in paraffin wax. These condensers have a larger capacity than the two Leyden jars used in the d'Arsonval apparatus. They are charged from the main, not from an induction coil. The positive and negative cables from the main are not connected directly to the condensers, because the latter would then be charged only to the voltage of the main supply, and this, at its highest, is not sufficiently high for the condensers. The voltage has therefore to be raised. This is done by means of a static transformer. The static transformer is described in detail on page 294, but we may say here that it consists of two coils of insulated wire, both wound on the same iron core, but separately and not in connection with each other. One coil, the primary, is made of a few turns of stout wire. The secondary is made of several turns of finer wire. The

current from the main is led through the primary. Currents are induced in the secondary, and their voltage and amperage will depend on the number of turns in the latter. The voltage is raised to about 2000. The current from the main must be an alternating current,

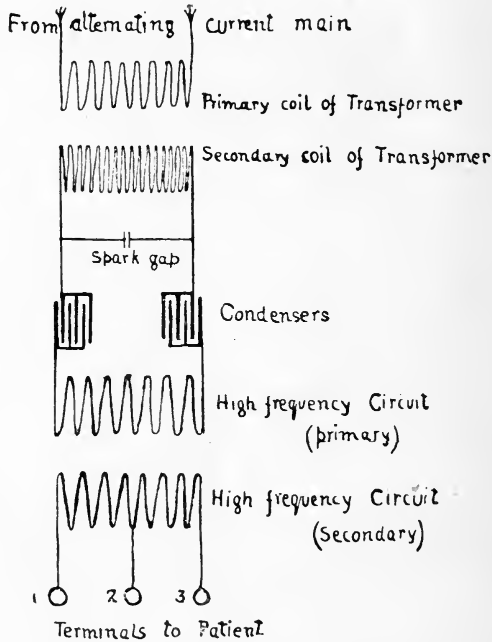


FIG. 51.—Diagram showing Circuits in a Diathermy Apparatus

because a direct current passing through the primary would not induce currents in the secondary. If the main supply happens to be a direct current, it must first be transformed into an alternating current by means of a motor transformer. The current that is supplied to the primary of the transformer may reach, say, 10 amperes, and the voltage at which it is supplied from the main

is 100. The latter is raised to 2000, and to this voltage the condensers are charged. Now in the d'Arsonval apparatus there is a transformer (viz. the induction coil with its iron core, and primary and secondary windings), but the current is transformed to a much higher voltage, 30,000 volts or more, which is unnecessarily high. Further, the primary of the induction coil is supplied by a current of less amperage, and, being a *direct* current, must be interrupted. It will therefore flow intermittently. Consequently there will be a smaller amount of electric energy supplied to the primary of an induction coil by the direct current than to the primary of a transformer by the alternating current.

The different circuits in the diathermy apparatus are shown diagrammatically in Fig 51. The condensers are charged from the secondary of the transformer. They discharge across the spark-gap and the solenoid is traversed by high-frequency currents. The spark-gap is quite different from that used in the d'Arsonval apparatus. The discharge takes place, not between two metal rods, but between large metal discs that are very closely opposed to each other without actually touching. There are two of these gaps placed in series. The discs are made of copper and their opposing surfaces, between which the sparks leap, are faced with silver. Each gap is about 0·4 millimetre wide.

The high-frequency current that is to be applied to the patient is taken, not from the solenoid directly, but from another separate coil that can be placed in close apposition with it, and so receive high-frequency currents by induction. This latter coil is the secondary high-frequency coil. A hot-wire ampere-meter is included in the circuit containing the patient and the latter coil.

When an alternating current from the main is supplied to the primary of the transformer, the condensers are

charged and discharged at an extremely rapid rate, far more rapid than that at which the Leyden jars in the d'Arsonval apparatus are charged and discharged. The discharge across the spark-gap causes a crackling, hissing sound. The sparks are, as it were, spread out over a large area, and instead of the bright, white, noisy sparks seen in the gap of the d'Arsonval apparatus, a film of non-luminous blue light occupies the narrow gap between the opposing metal discs. If wires connected to the extremities of the secondary high-frequency coil are brought close together a torrent of thick, white, noisy sparks passes between them.

FIG. 52
Diathermy Machine by Dean

A diathermy machine by A. E. Dean is shown in Fig. 52. The transformer, condenser and high-frequency coils (primary and secondary) are enclosed within the case

that forms the body of the machine. The cover of the case is formed by a marble slab, on which are fixed the ampere-meter, the spark-gap, the handles for regulating the currents, a switch for cutting off the current supplied to the machine and terminals for leading the diathermy current to the patient. The spark-gap is covered by a U-shaped metal cage, so as to protect the operator from burns which might be caused by accidentally touching the metal discs.

Other models of diathermy apparatus have been designed. They all work on the same general principle and differ chiefly in the method adopted for regulating the strength of the current and in the construction of the spark-gap. In the machine illustrated the high-frequency current is regulated by bringing the secondary high-frequency coil more or less closely in apposition with the solenoid. This is effected by rotating the handle shown on the right-hand side of the marble slab. A crank, shown on the left-hand side, regulates the amount of current supplied to the transformer and so increases or diminishes the output of the machine. In other machines the current supplied to the transformer is regulated by means of a variable resistance that is included in series with the primary coil; while in some machines the high-frequency current to the patient is regulated by taking a varying number of turns of the secondary high-frequency coil into circuit.

Physiological Action of Diathermy.—The sustained high-frequency currents supplied by the diathermy machine raise the temperature of the tissues which they traverse, and such physiological effects that have been observed to follow applications of diathermy are the result of this rise of temperature. The subject has not yet received much experimental investigation. Réchou made some observations on the respiratory exchange of

a subject during the application of diathermy (quoted by Bergonié, *Archiv. d'Elect. Med.*, 10th March 1913). He found that the first effect of the diathermy was to increase the intake of oxygen and output of carbon dioxide. As the diathermy continued it was found that the subject took in less oxygen and gave out less carbon dioxide. The first effect of the diathermy was to increase metabolism, evidently that concerned in the production of heat; the second effect was to diminish it, the artificial introduction of a large quantity of heat rendering unnecessary the production of the customary amount of heat by the body.

The application of general diathermy to the normal subject by means of electrodes grasped by the hands or embracing the forearms is followed by a sensation of heat. The heat is felt first in the narrowest part of the forearm; it then spreads up the arms; afterwards the whole body feels warmer, but the greatest heat is always felt in the lower part of the forearm, where the path for the current is narrowest and the resistance therefore greatest. The subject sweats profusely after the diathermy has been in progress for some minutes, more especially from the upper limbs and face, when the electrodes are applied to the forearms or hands. The frequency of the pulse rises and, in some subjects, the blood pressure falls. Occasionally the fall is accompanied by a feeling of faintness and the diathermy must then be stopped.

Proof of the Heating of the Deep Parts.—Experiments on animals have been carried out by various workers, and they show that the heat produced by the diathermy penetrates into the deep parts and is not confined to the skin. Thus the hind limbs of animals have been coagulated in their entirety. Electrodes have been placed on the exterior of an animal's skull and the diathermy

current passed through the brain. A thermometer with its bulb in the lateral ventricle showed, in one experiment, a rise of 1° centigrade after ten minutes' diathermy.

In the human subject investigation of the subject is more difficult. The author was able to show, in one case, a rise of temperature of 1·2° F. in the posterior fornix vaginæ after application of diathermy to the pelvic region by way of electrodes placed over the hypogastrium and under the gluteal region.

How Diathermy is applied to the Body.—Diathermy may be applied so as to raise the temperature of the whole body (general diathermy), or of part of it (local diathermy). The passage of the diathermy current through any part heats not only the fixed tissues, but also the blood that circulates through them, so that if the application of the current is for long, and particularly if a large part of the body is traversed by the current, the temperature of the rest of the body will be raised by means of the heated blood. Therefore the local treatment becomes, to a greater or lesser degree, a general treatment as well.

(*a*) *General Treatment.*—This may be given on a special form of condenser couch. It was designed by Schittenhelm, and is shown in Fig. 53. The patient lies on sheet ebonite one-eighth of an inch thick, placed on the framework of the couch. Under it lies a large metal sheet divided into four separate parts. One lies under each lower extremity and one under each shoulder and corresponding side of the trunk. The cables from the diathermy machine are connected to two terminals at the head of the couch. A "changing box" is fixed to the head of the couch. In it are enclosed five cranks, and each of the four parts of the metal sheet is connected to one of these. By turning these cranks into the appropriate positions it is possible to connect either cable from the diathermy machine with any division or divisions of

the metal plate. Suppose that one cable is connected to the division under the right shoulder, the other to the

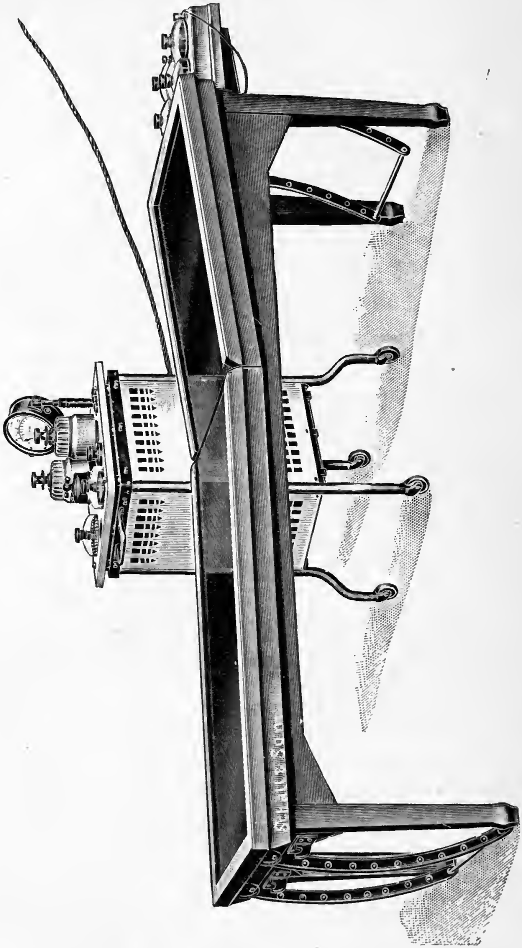


Fig. 53

division under the right lower limb. Each division will then become alternately positively and negatively

charged, the frequency of the alternation of the charge corresponding to the frequency of the oscillation of the diathermy current. Charges will be induced on the parts of the body in contact with the ebonite sheet over the metal plates. These induced charges will change their sign synchronously with the inducing charges. Consequently induced currents will oscillate through the body between the right shoulder and the right lower limb. By suitable arrangement of the cranks in the changing box the currents may be made to oscillate between shoulder and shoulder, or between *both* shoulders and *both* lower limbs, or in any other direction.

When applying diathermy on the condenser couch the patient need not remove clothes, but metal, such as coins or keys in the pockets, and watch and chain, are best removed, also corsets, if they contain metal. He gradually experiences the sensation of warmth, and it is first felt in the parts in contact with the couch. A watch should be kept on the pulse and blood pressure, for occasionally the latter falls and the patient feels faint. The treatment must then be stopped.

(*b*) *Local Treatment.*—The part to be treated is enclosed between two electrodes placed on opposite sides. In the case of limbs, they may be placed above and below. The electrodes are made of metal plate, and are of different sizes and shapes, oblong, square or circular. They should roughly approximate in size and shape to the part to which they are applied. The metal plates may be placed in direct contact with the slightly damped skin, or an absorbent pad about one-fourth of an inch in thickness, soaked in salt solution, may be interposed. With the latter device a better contact may be ensured when the surface is irregular. Tap-water must not be used to soak the pads with, as it does not contain sufficient saline substances in solution (ions) to conduct the current readily. If used, the electrodes become

gradually hotter and may cause burns. The strength of the salt solution should not be less than 10%.

When the electrodes are securely bandaged in position the current is turned on and gradually increased till the patient begins to perceive warmth. The warmth gradually increases and the current may be afterwards further increased till the heat is as much as can be borne without discomfort. The patient's sensation is a sufficient guide to ensure diathermy without burns, but if there is anæsthesia, diathermy cannot be applied without some risk. Nagelschmidt has composed a table showing the maximum current that can be safely borne by the skin with different size electrodes. The latter must make the best possible contact with the skin and the current should not be applied at once in the maximum permissible strength.

Local treatment may also be given on the condenser couch. A terminal on the changing box is connected to an electrode that is placed on the part requiring local treatment. By means of one of the cranks in the changing box this is brought into connection with one of the cables of the diathermy machine. The other cable is brought into connection with one or more of the metal plates under the ebonite sheet. By this method the part requiring local treatment will be very effectively heated, while, at the same time, the other parts will receive a less intense but more general treatment. This method is particularly suitable when a large portion of the body, such as the chest or abdomen, is to be subjected to diathermy.

In the absence of a condenser couch, general treatment may be given by applying two electrodes, one to each forearm. The current therefore passes along the arms, across and between the shoulders. In this way the temperature of the arms is raised, while the heated blood passes to the rest of the body and gradually raises its

temperature. Electrodes may then be applied to the legs, so that the current passes along them and across the pelvis, producing local and general heating as before. The current may be directed simultaneously from arm to arm and from leg to leg, by attaching electrodes to each part and using double or bifurcated cables.

Special electrodes are made for diathermy of special parts. Metal tubes with closed, rounded ends are used for insertion into rectum or vagina. Vacuum electrodes, the same as used for high frequency, may also be used for local application, so as to combine the action of the diathermy with that of the ozone and oxides of nitrogen. These electrodes are described in the preceding chapter.

Medical Diathermy.—The application of diathermy to medical cases has not been practised long enough in this country to allow a definite statement of the morbid conditions for which it is to be applied. Maladies and morbid conditions that are likely to benefit from application of heat, are likely to improve further by diathermy. Heat as ordinarily applied warms the skin only. The sustained high-frequency current heats the deep parts as well as the superficial, whereas other methods produce only surface-heating or "epithermy." Inflammation of nerves, joints and serous membranes, accompanied by pain, are often relieved by diathermy. Diathermy seems to be very successful for cases of gonorrhœal arthritis. The gonococcus is apparently sensitive to small rises of temperature. By the diathermy current the joint is heated through.

The temperature of the whole body can be raised by general diathermy, and brought into a state of "physiological fever." The condition of lowered vitality, in which there is depression of the functional activity of the organs—cases to which the name "misère physiologique" has been applied—are much benefited by general

diathermy, which supplies the heat that the body cannot supply, in its state of impoverished vitality. Nagelschmidt claims that diathermy can lower abnormally high blood pressures. He applies one electrode to the precordium and another to the back. Angina pectoris is said by the same writer to benefit by similar treatment.

Surgical Diathermy.—By means of the diathermy current it is possible to raise the temperature of the tissues sufficiently high to destroy their vitality. They can be coagulated in situ. The diathermy current can therefore be used to destroy new growths, both innocent and malignant. The coagulation is due to the heat that is produced within the tissues as the current traverses them. Such instruments as the galvano-thermo-cautery and the Paquelin cautery simply char the tissues locally, and, as the latter conduct heat very badly, there is very little spread of coagulation beyond the carbonised cavity. The tissues conduct electricity well, and, as it is the electricity that develops the heat, there is not this limitation to the spread of the coagulation. It is therefore easy, by means of the diathermy current, to coagulate a malignant growth in its entirety "through and through."

The rise of temperature necessary to coagulate a growth is brought about by reducing the size of the electrode in contact with the growth (the active electrode) to that of a needle or small disc or button. The other electrode (the indifferent electrode) covers a large area of skin. The current density will be greatest at the point where the current leaves the electrode to enter the tissues, and there the temperature will reach the highest. As the distance below the surface increases, so the current density lessens and the temperature diminishes. For a certain distance below the electrode the tissue is coagulated.

The depth to which coagulation spreads depends, apart from the time during which the current flows, upon the shape and size of the active electrode and the vascularity of the tissue. The larger the surface of contact between the active electrode and the tissue, the greater will be the depth to which coagulation will extend. If a small surface electrode is used the current density is great at the point of contact with the skin, and the temperature there very quickly rises to a point at which the tissue is dried. Dried tissue conducts the current badly and sparks make their appearance and the current has to be switched off soon after it is started, so that there is no time for the coagulation to spread far. The depth to which coagulation spreads depends also on the vascularity of the tissue. The circulating blood tends to dissipate the heat and may prevent coagulation in the region where the temperature would be, in less vascular tissue, just sufficient to cause it. As an approximate guide, it may be taken that the coagulation will spread below the electrode for a distance equal to the diameter of the latter.

Electrodes.—The most generally used *active* electrode consists of a short rod-shaped ebonite handle with a metal core. Into the proximal end of this is screwed one of the cables leading to the diathermy machine. To the distal end is attached a metal end-piece. The latter is usually a disc or button, bearing sometimes one or more short metal spikes. Special end-pieces have been designed for less accessible regions, such as the larynx and œsophagus. The *indifferent* electrode is composed of a pad of lint or folded towel measuring 12 inches by 8 inches. It is soaked in strong salt solution and placed on the chest or abdomen. On it is placed a piece of sheet lead one sixteenth of an inch thick and 8 inches long and 6 inches broad, and to it is connected one of the cables from the diathermy machine.

How Surgical Diathermy is performed.—An anæsthetic is required except when very small portions of tissue have to be destroyed and the applications are momentary. A general anæsthetic is required if the tissue to be destroyed lies in a less accessible region, such as the mouth and throat, and if a large mass of tissue has to be destroyed. A local anæsthetic may be used in some cases. The electrodes are placed in position, the indifferent electrode on the chest or abdomen, the active electrode on the growth. The current is then switched on and gradually increased. Bubbles of gas are seen escaping from the region of the active electrode and the tissue under the latter whitens from coagulation. The current is then switched off and the electrode placed on an adjoining part. The current need not be further adjusted, but it is merely switched on till coagulation has again taken place. In this way the whole of the growth is coagulated. If the growth is fungating it may be necessary to gently scrape off the coagulated tissue and coagulate further till it is thought that healthy tissue has been reached.

Advantages of Diathermic Coagulation or Cautery.—The operation is quick and patients do not suffer from shock after it. They are able to get up after forty-eight hours in most cases and leave hospital in a few days. The blood vessels and lymphatics are sealed by the coagulation of their contents. Oedema of the surrounding parts comes on during or soon after the operation and a copious discharge of lymph sets in and lasts some hours. The coagulated tissue sloughs away and the cavity quickly fills with granulation tissue. A point of special interest is the absence of adhesions at subsequent periods.

Results.—Diathermy has been used of late for the treatment of *inoperable* malignant growths. Many of

these have been made to disappear, and although recurrence takes place, this event has in many cases been postponed for a year or even longer. One patient with an inoperable growth of the tonsil and fauces lived as long as two years and nine months after the first application of diathermy. It is always necessary to keep the cases under observation and reapply the diathermy when recurrence is noticed. The patient referred to had six applications. Other cases show recurrence at an earlier date, but considerable improvement is the rule, and the relief from distressing symptoms, such as pain, discharge and constant expectoration when the growth has involved the mouth and throat, is a common occurrence.

Diathermy would give its best results in the treatment of *operable* growths. There is no reason why removal with the knife should not follow diathermy, as the destruction of the main mass of the growth and the sealing of the blood vessels and lymphatics would minimise chances of dissemination.

Diathermy has also been tried for non-malignant growths. It has given good results in cases of large nævi. Nævi of the mucous membranes are more suitable than nævi of the skin. For papillomata of the bladder it would seem the treatment *par excellence.* Each papilloma is in turn brought into view by the cystoscope and an insulated wire is passed along the channel intended for the catheter to the ureter. It makes contact with the papilloma and the current quickly coagulates it.[1]

[1] For a more complete account of diathermy see *Archives of the Rœntgen Ray*, July, 1914, *et seq.*

CHAPTER XIII

THE USE OF STATIC ELECTRICITY

Apparatus required.—The first requirement is a generator of static electricity, or, as it is called, a "static machine." The old frictional generator has been long discarded and its place has been taken by the so-called "influence machines." There are two principal kinds, the Holtz machine and its modifications and the Wimshurst machine.

The Holtz machine is very popular in America, but it possesses at least two distinct disadvantages. It has first to be given an initial charge from a small Wimshurst before it will start generating, and it is also sensitive to the changes of the weather.

The Wimshurst Machine is self-exciting and has no tendency to reverse during action, and on this account is most popular in this country. With some machines of this type one can never be sure beforehand which pole will be positive and which one negative, but once started the polarity will not change during the continuance of the run. It is not so sensitive to changes of the weather. In very damp weather, if it is not enclosed in an air-tight case, its output will be reduced and it will not be self-exciting. Fig. 54 shows a small Wimshurst.

It consists in its simplest form of two circular glass plates, each mounted on the end of a hollow boss of wood upon which a groove is turned to act as a pulley for driving the plate. The wooden bosses with the plates are mounted in a horizontal steel shaft, so that the plates are

facing each other and about one-eighth of an inch apart. Directly below the plates is another horizontal shaft, upon which are secured two large wooden pulleys exactly opposite the grooves turned on the wooden bosses. A handle is provided at one end of the lower shaft, and two leather belts, one of which is crossed, are fitted round each pulley and its corresponding boss. When the handle is turned the plates will revolve in opposite directions. The plates are well varnished, and attached to their outer surfaces are a number of radial sectors of tin-foil or thin brass. These are equally spaced all round the discs—they make the machine more easily self-exciting, but are not essential to its action, especially in the case of larger machines. By means of a neutralising rod tipped with a fine wire or tinsel brush at each end, mounted so as to be adjustable concentrically with the shaft upon which the plates revolve, each pair of sectors at opposite ends of a diameter are placed momentarily in metallic contact twice during each revolution. These neutralising rods must be adjusted to the point of maximum efficiency, which will be readily found by experiment. If we stand facing the plate, and its direction of rotation be clockwise, the neutralising rod will be in the position of the hands of the clock indicating *five minutes to five*. This will vary in different machines, but the correct position will be found very near this point. The fixed conductors are mounted at the ends of the horizontal

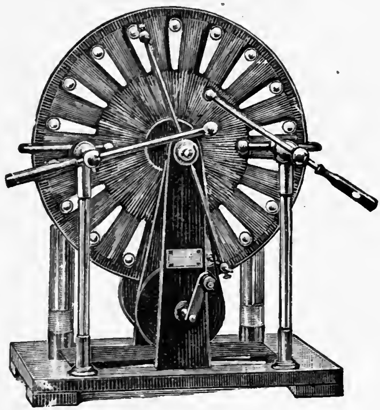


FIG. 54.—Wimshurst Machine

diameter and consist of two forks, with collecting points on the inside pointing towards each other, and the plates revolving between. These forks are mounted on ebonite or glass pillars, and to each fork is attached an electrode consisting of a metal rod bearing a brass ball at one end and an ebonite handle at the other. The electrodes are movable, and an operator can grasp the insulating handles and move the electrodes, so that the brass balls can be brought closer together or farther apart. The collecting device with the discharging apparatus is sometimes called the "prime conductor." When the plates are revolved, positive electricity collects on one electrode, negative on the other. If the electrodes are sufficiently close together a succession of fine crackling sparks passes across the intervening gap. With a large machine the sparks may be many inches long. The difference of potential between the charges on the two electrodes reaches a very high value.

As usually supplied, the machines have a Leyden jar attached to each electrode, the latter being connected to the inner coating of the jar. When their outer coatings are connected together and the machine set in action the character of the discharge is completely altered. Instead of the soft crackling brush, the discharge takes place at definite intervals and each is accompanied by a more or less loud report.

The Leyden jar greatly increases the capacity of the electrodes, so that they can take much larger charges, but a longer time elapses before these larger charges reach a potential sufficiently high to overcome the resistance of the air between them. A loud, intensely white, thick spark accompanies the discharge.

A shock from a large machine with the jars connected might be fatal. The jars are, in most cases, to be disconnected before any static machine is used for treating patients.

There are made by some manufacturers various modifications of the Wimshurst. One has ebonite plates, and, on account of the toughness and flexibility of the material, the plates can be driven at a very high speed. Another has plates made of compressed mica, which can also be driven at a high speed. The advantage of high speed is that the same difference of potential can be obtained with a smaller plate, making the machine less bulky. The disadvantages of ebonite are that it often becomes bent and buckled out of shape. Also its insulating properties become very much impaired after a time, and the output of the machine correspondingly reduced.

For medical purposes the Wimshurst machine should have not less than eight plates, thirty or thirty-six inches in diameter. The machine should be enclosed in an air-tight case with glass windows, so as to prevent the attraction of particles of soot and dust from the atmosphere. The air inside the case can be dried by desiccators, such as boxes of quicklime or trays of sulphuric acid. The machine is driven by a small electric motor, or a gas or oil engine.

Glass coated with shellac is at present the most suitable material for the plates. Ebonite is lighter, and plates made of this material can be driven at a higher speed than glass, so that electricity can be generated at a quicker rate. But ebonite deteriorates after a time, as chemical changes take place on its surface and impair its insulating properties. It loses its black colour and acquires a greenish tint. Further, it tends to warp, so that the plates come in contact as they revolve.

The Wimshurst machine has the following advantages. As soon as the plates begin to revolve it begins to generate electricity. The other machines will not generate electricity when the plates are made to revolve, unless an initial charge has been given to it first. The Wimshurst machine is less sensitive to damp than the others.

The Holtz Machine.—In its simplest form this machine (Fig. 55) consists of two vertical glass plates, one of which (*A*) is fixed, while the other (*B*) can revolve parallel to it. The plates are close together, but do not touch. The fixed plate is slightly larger than the revolving plate. In the fixed plate are cut two "windows" (*a* and *b*) diametric-

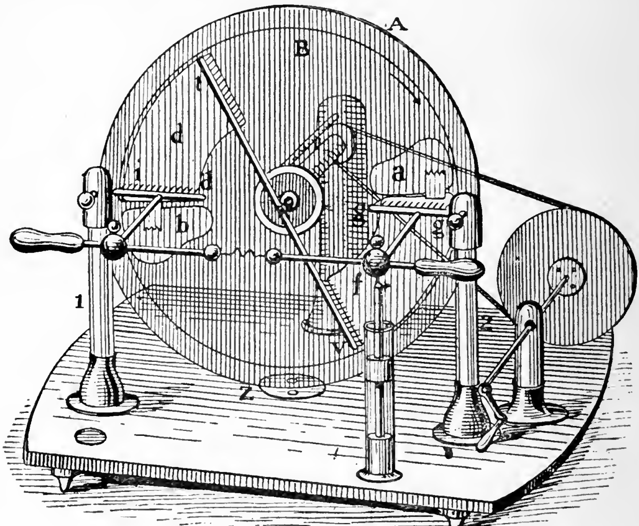


FIG. 55.—Holtz Machine (from *Electrical Influence Machines*, by J. Gray)

ally opposite each other. Two pieces of paper, known as "field plates," are fastened on to the fixed glass plate, one (*d*) being placed above the window (*b*), the other being placed below the window (*a*). A strip of paper attached to each of these field plates projects through the window on the same side and points at the revolving plate without touching it. The latter plate revolves in a direction opposite to that in which the strips point. Two metal rods (*g* and *i*), bearing metal spikes, collect the electric

charges from the revolving plate on to the metal balls shown in the figure. Two of these balls, mounted on the ends of brass rods with insulating handles, are movable, and can be brought closer together or farther apart. They are made to touch when the machine is to be started. The rod *tv*, known as the "neutralising rod," carries a comb at each end, the points of which are directed towards the front of the revolving plate.

To start the machine, an electric charge from a rubbed ebonite rod is given to one of the field plates. The movable plate is then revolved and the balls drawn apart. Sparks then dart across the gap separating them.

The modern form has six or eight plates, arranged in pairs, each pair consisting of one fixed and one revolving plate. It is enclosed in an air-tight case and is driven by a motor like the Wimshurst machine. An initial charge of electricity must be administered to one of the field plates of the Holtz machine before the plates are made to revolve, otherwise no electricity will be generated. A very small Wimshurst machine is usually placed in the case to generate this initial charge.

The Toepler machine (known also as the Voss machine) works on the same principle as the Holtz; it is usually self-starting, requiring no initial charge.

The Baker paper-disc machine is much used in America, and those who have used it in this country speak favourably of it. It is a modified Toepler machine. The stationary plates, four in number, are made of glass. The four revolving plates are made of paper. Each plate is composed of twenty-four discs of paper saturated in shellac and other gums, compressed together between hot metal discs. These plates are light, unbreakable and do not readily condense moisture on their surfaces, and so their insulating properties are not impaired. They can be rotated 2000 times per minute. The usual rate with glass plates is 350 per minute. The machine is enclosed

in a case and driven by a motor. It requires an initial charge before it generates further quantities. A small Wimshurst machine is provided for the purpose. Outside the case enclosing the static machine are the two prime conductors. The latter are fitted with sliding rods bearing a brass ball at one end and an ebonite handle at the other. The air space between the brass balls is the spark gap and its length can be regulated by the sliding rods.

Static machines are usually provided with a pair of Leyden jars. One is connected with each prime conductor. In most methods of applying static electricity to patients they are not used and should be disconnected.

Accessory Apparatus.—The accessory apparatus includes an insulating platform, a set of electrodes, lengths of brass chain for connecting the electrodes to the prime conductors or to other parts where necessary, and a long brass rod bent to a hook at one end, like a shepherd's crook, for the purpose of connecting the patient to the machine.

The insulating platform supports the patient. It is mounted on four stout glass legs. The legs should be coated with shellac to prevent the condensation of moisture on them, which would impair their insulating power. They should be at least ten inches long. When powerful machines are used, the platform should be raised thirteen inches off the ground by its insulating legs. The wooden framework should have all corners and edges rounded off. The platform should be large and strong enough to support the heaviest patient. It should measure 5 feet by 2 feet 4 inches. The patient sits on a chair on the platform. The chair should contain no metal, and all edges should be rounded off. The patient must sometimes be in a reclining position. When this is necessary, the chair should be replaced by a wicker couch.

Four common types of *electrode* are shown in Fig. 56. Each consists of an ebonite handle with a metal end-piece. The latter may be a metal rod, tapering to a point, or it may terminate in a metal disc bearing a number of metal spikes. These are known as the single-point and multiple-point electrode respectively. The metal may terminate in a brass ball (ball-electrode) or may carry a metal roller (roller electrode). The metal portion of each

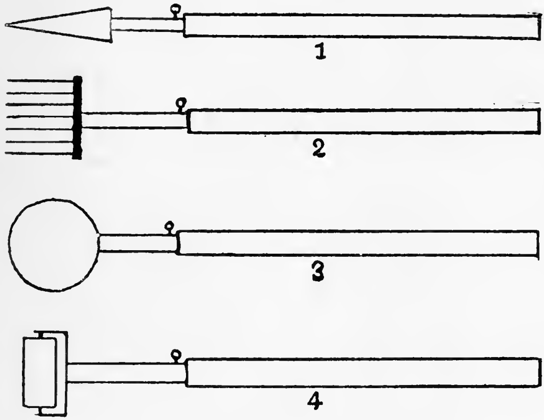


FIG. 56.—Electrodes for use with Static Machine
1. Single-point (metal) electrode
2. Multiple-point (metal) electrode
3. Metal ball electrode
4. Roller electrode

electrode bears a small metal ring, to which may be attached the brass chain connecting it to the machine.

These electrodes have been modified in various ways. Thus, the handle may be made of some partially conducting material, such as wood that can absorb a certain amount of moisture. It may terminate in a metal or wooden point. The chain that connects this electrode with the static machine is attached, not to the metal end, but to a short length of metal tube that slides over the

handle, and its position can be adjusted so as to include a greater or smaller length of wood between it and the tip of the electrode. This electrode has been used especially for the application of the static breeze (see below).

The Machine in Action.—When the motor is started and the plates are revolving, positive electricity collects on one prime conductor, negative on the other, and when the sliding rods are brought towards each other sparks pass between them with a frequency that increases the closer the rods approach one another.

It is necessary to know the prime conductor on which the positive and on which the negative electricity accumulates, because each time the machine is started the same prime conductor does not invariably charge up the same. A convenient way to "test the polarity," as it is called, is to proceed as follows. Start the machine and bring the single metal point electrode gradually nearer to one or other of the prime conductors. The point electrode should be connected to earth by a chain attached to the ring on the metal part of the electrode, and at the other end to a water or gas pipe, or the floor of the room if of wood or stone. Gradually bring the point of the electrode nearer and nearer, and, as it approaches the positive prime conductor a star of light will appear on the point, even at a distance of several inches, and this star of light will remain without much alteration until the point is brought up almost in contact with the knob; then small sparks pass. If approached to the negative prime conductor in the same way, the discharge takes the form of a visible brush of non-luminous noiseless sparks when the point is still at a distance of two or three inches from the knob. It is easy to recognise these differences in the discharge to the point, and from them to know which prime conductor is positive and which is negative.

Static electricity means, literally, electricity "at rest." It is, however, only at rest when it is on the prime conductor and not leaking off. When it is applied to the body it flows on to and off from the latter. The body is alternately charged and discharged in some of the applications, so that static electricity becomes "current electricity." The current, however, is extremely small, not greater than a fraction of a milliampere, although its voltage is exceedingly high, reaching half-a-million or more.

The Methods of Applying Static Electricity to the Patient.—The Static Bath.—In this method of application the patient is merely charged with electricity. He sits on a chair on the insulated platform. The chair should contain no metal. The patient is connected to the positive prime conductor of the machine by means of the metal rod with the crook at the end. The end is hooked over the sliding rod of the positive conductor, while the other end is placed on the floor of the insulated platform, not in contact with the patient or the chair. The patient and the insulating stool should be at least two feet away from the machine or from the walls and other objects. Before connecting the platform with the machine, the latter should be set in action and the polarity tested. The sliding rods are then placed in contact, and the platform is connected to the positive prime conductor. The sliding rods are then drawn as far apart as possible. The patient is charged positively, and when the voltage of this charge reaches a sufficient height the electricity leaks off from the surface of the body. The sensation is agreeable, and the skin feels as if it were in contact with cobwebs. For a stronger effect, or if the machine is not powerful, the end of the crook should be placed on a sheet of metal on the platform and two of the legs of the chair should rest on it. For a still stronger

effect, the feet of the patient should rest on the metal plate. When the patient actually holds the metal rod the effect is strongest of all. The latter method of con-

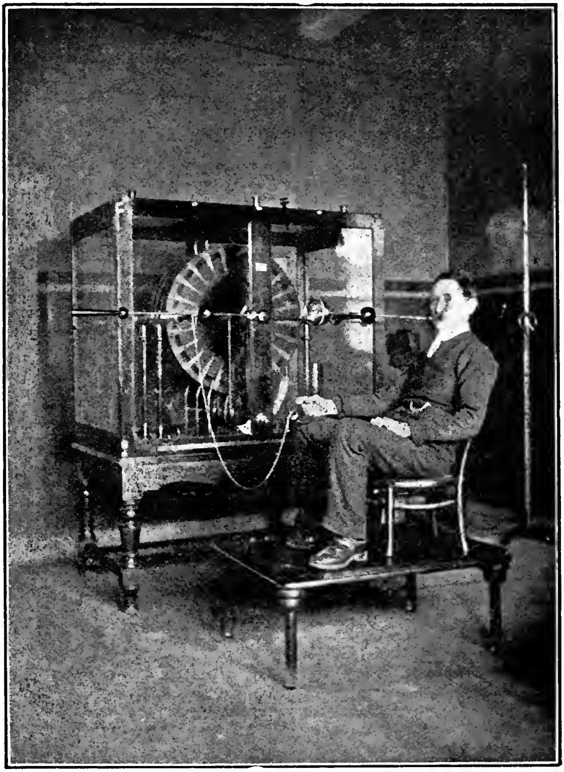


FIG. 57.—Stati Breeze

nection between prime conductor and patient is to be adopted when powerful machines are not available (Fig. 57).

Treatment may be continued for fifteen minutes or

longer. It is the mildest form of static electrical treatment and it produces no unpleasant sensations. It is indicated for hypersensitive, nervous patients for the production of tonic effects.

Its beneficial effects are possibly due to gentle stimulation of the sensory nerves of the skin, caused by the continuous leakage of the charge from the surface of the body.

Another method of giving the static bath is to charge the patient positively as before, and then bring the negative sliding rod gradually nearer to the positive till a spark passes; at this moment the patient is discharged, but is quickly recharged and again discharged, and so on. A stream of sparks passes between the balls on the end of the sliding rods. The rate at which the sparks follow each other depends upon the width of the spark-gap and the rate at which the electricity is generated. The width of the gap should be adjusted so that the sparks pass apparently continuously. The patient should be arranged on the chair on the platform with the feet on the metal plate, the latter connected by the brass rod with the positive prime conductor. If there is a sensation of sparks on the feet the boots should be removed.

This modified method is rather more vigorous than that of simple charging. It is known as the method of "potential alternation" or "interrupted electrification." The sparks cause a continuous noise that is disagreeable to some patients.

The Static Wave Current.—This is known also as the "Morton wave current." To apply it, the patient sits on a chair on the insulating platform. An electrode made of pliable sheet metal cut to the desired shape is applied to the part requiring treatment and connected to the positive prime conductor of the machine by means of a

wire. The negative prime conductor is earthed by means of a brass chain connected to a water or gas pipe or radiator, or to a wooden or stone floor. The arrangement is shown diagrammatically in Fig. 58. The machine is started and the negative sliding rod is gradually separated from the positive. Sparks at once bridge the gap. With each spark there is a contraction of the

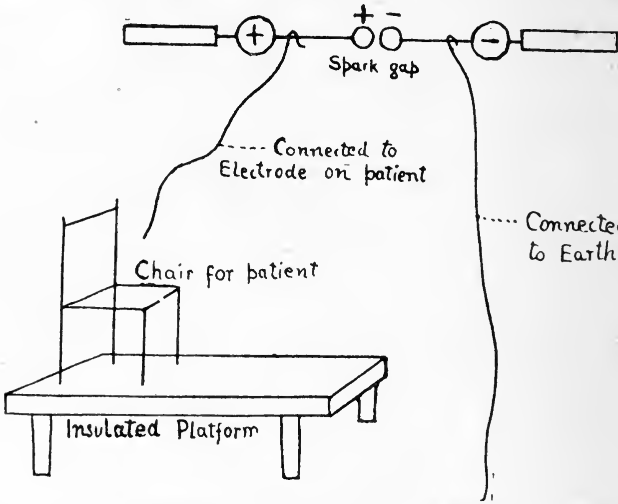


FIG. 58.—Arrangement of Apparatus for application of Static Wave Current

muscles of the part under the electrode. If the sparks follow each other with sufficient rapidity the muscles are tetanised. If the sliding rods are further separated the sparks pass with less rapidity, but the contractions become stronger. It is therefore advisable to have some device whereby the frequency of the sparks may be regulated. To some static machines is fitted a device called the "Baker field regulator." It is fitted to the Baker paper-disc machine and controls the frequency of the sparking. Such control is necessary for the successful

application of the static wave current. The gap should be widened till the contraction with each spark is as strong as can be comfortably borne. The field regulator is then adjusted so as to give about three sparks per second.

If there is no field regulator attached to the machine the frequency of the sparks may be lowered by placing a chair close to the insulated platform adjusting the distance till the frequency of the sparking reaches the desired rate. Another way is for the operator to bring an earthed single-point electrode to a suitable distance from the platform.

The electrode that is applied to the patient may be made of thin pliable sheet metal, such as lead. It can be cut to the shape and size required and applied to the skin of the part requiring treatment. It should make good, even contact, and if the skin is dry it should be moistened with soap and water. The static wave current can be applied to the rectum, uterus and prostate. Special electrodes have been designed for these parts. They are made of metal bulbs with hard rubber insulating handles. The bulb is passed into the rectum and the rubber handle remains outside and held by the patient in the correct position. If the uterus is to be treated, the electrode should be held so that the metal bulb is in apposition with it through the rectal wall. If the prostate is to be treated, the metal bulb is hollowed out partially, so as to make a better apposition with the gland through the rectal wall.

When the patient is connected to the machine in the way described for the application of the static wave current, the body is charged positively—the electricity passing on to the body by way of the electrode. At the same time, the negative charge from the other prime conductor passes to earth. When the difference of potential between the latter charge and that on the body

reaches a sufficiently high value, the resistance of the air space at the spark gap is overcome, the two charges neutralise each other, a spark passes across the gap and the body is suddenly discharged. The electricity leaves the body by way of the electrode. The body is alternately charged and discharged, the discharge being sudden and brisk and the charge relatively slow. Each time that the discharge takes place the muscles under the electrode give a sudden twitch. The current is therefore a to-and-fro surging of electricity to and from the body by way of the electrode.

The static wave current has been recommended for a large number of maladies in which the morbid condition is inflammation with congestion and exudation. Good results have been claimed in cases of sprained joints, inflammatory swelling of the prostate, dysmenorrhœa with congestion of the uterus, and in diseases of other parts in which there is the same pathological condition.

The mode of action of the static wave current is most probably mechanical, the sudden forcible rhythmic muscular contractions aiding the local circulation and removing inflammatory products.

The Static Breeze (Static Brush).—If when the patient is charged from one conductor the single or multiple point electrode is connected to the opposite pole and brought near to him, the electricity passes between the points and the body. There are no sparks like those that pass between the prime conductors, but a cone of non-luminous blue-violet light bridges the gap between the points of the electrode and the skin of the patient. There is a faint blowing sound and the patient is conscious of a cool breeze blowing upon him ; hence the name " static breeze."

To apply the static breeze, the patient is arranged as for simple charging and connected to the positive prime

conductor. The single or multiple point electrode and the negative prime conductor are connected to earth (Fig. 59). The electrode is grasped by the operator and the points are directed towards the part of the patient requiring treatment. As it approaches closer the sensation perceived by the patient loses its cool character, and when the electrode is still closer there is the feeling as of a fine

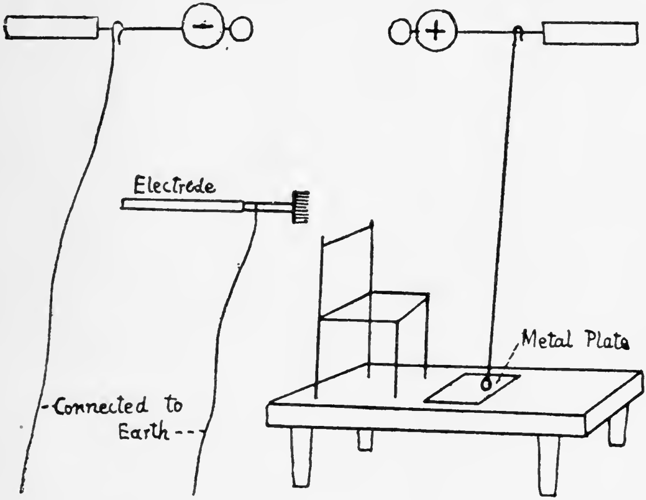


FIG. 59.—Arrangement of Apparatus for application of Static Breeze

spray of hot water. If the electrode is placed very near the skin, sparks may pass and cause pain. If the brush is directed on to one spot of the skin without changing its position, a blister may be produced. For applying the breeze to the scalp, a light crown-shaped metal electrode is often used. It is suspended above the patient's head, either from an insulated pole or from a rod pivoted to the case of the machine. It is connected to the negative prime conductor.

If the skin is covered by a dry cloth or by the ordinary

clothing, the breeze produces a still hotter sensation, which may be painful. The skin should not be damp with sweat, otherwise the breeze will lose some of its effect. If necessary, the skin may be bared and then covered by a shawl, upon which the breeze may be directed.

It is thus possible, by means of the static breeze, to produce any degree of cutaneous stimulation, slight, with agreeable sensations, to a burning, tingling sensation causing pain. The stimulation of the peripheral sensory nerves causes a reflex rise of blood pressure, and it is to this that the good effect following treatment by the static breeze is chiefly due when applied for *general* effects. Patients whose pressure is raised are not likely to benefit from the static breeze. Those whose symptoms (*e.g.* headache) are the result of a low pressure are greatly benefited and headache will often disappear during the application. The breeze, applied locally, has often a healing effect on chronic ulcers, bringing about hyperæmia and, possibly, disinfection by means of the ozone and oxides of nitrogen produced. In other skin affections, such as pruritus, eczema and psoriasis, it often produces good results.

Static electrical applications, especially when the breeze is applied to the lumbar and sacral region, have a beneficial influence in cases of menstrual irregularity and amenorrhœa.

Electrical Sparks.—If the point electrode is replaced by the ball electrode the discharge between the patient and the latter does not take place in the form of a brush, but of noisy sparks. The sensation is not pleasant and resembles that of a sudden blow. To administer sparks, the patient is arranged again as for simple charging and the ball electrode connected to earth is brought close enough to allow the discharge to take place. As the

sparks produce an unpleasant sensation it is best to manipulate the electrode so as to allow only one spark at a time to pass. This is done by making the electrode describe a curve past the place on which it is desired that the spark should be directed, and if the manipulation is skilful and rapid the electrode is out of range before a second spark can pass.

The length of spark administered should vary according to the part to be treated, longer sparks, ten inches or more, for larger parts, such as the hip or thigh, and shorter sparks down to half-an-inch for smaller regions, such as the wrist or finger. The length may be diminished by slowing the rate of revolution of the plates and by using small-size ball electrodes ; and the length can be further diminished if the operator places his foot close to the insulating stool. The patient should always be warned before the passage of a spark.

Treatment by means of static sparks is of value in some cases of lumbago and pain in the muscles, sometimes relieving the pain instantaneously. Probably the muscular wrench removes deep-seated congestion and breaks down adhesions.

A modification of the sparking method consists in the use of a roller in place of the knob. It is rolled over the *clothed* surfaces of the skin and a shower of stinging sparks passes to the patient. The thicker the layer of clothing the more intense the effect. In employing this method the operator should first place one foot on the platform before placing the roller in position, and also before removing it. In spark applications it is a good rule to always warn the patient of what is coming. Sparks from the roller cause intense sensory stimulation, with muscular contraction.

Short static sparks are useful for the discovery of tender points in the region of joints and along the course of nerves. Where the patient complains of general pain

all over, an administration of sparks will reveal the presence of tender spots; to these spots subsequent treatment may be specially directed.

The Static Induced Current.—This current must not be confused with the static *wave* current. Two Leyden jars are introduced into the circuit, in series with the

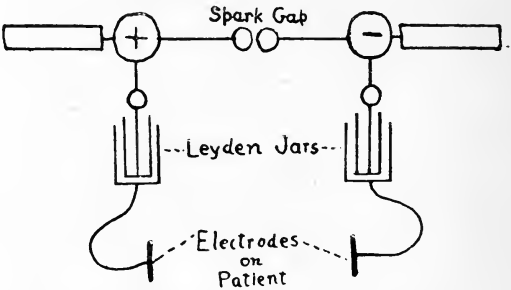


FIG. 60.—Arrangement of Apparatus for application of Static Induced Current

patient (Fig. 60). The inner coats are connected one with each prime conductor. The outer coats are connected by a wire. If the machine is now started and the sliding rods drawn a short distance apart, sparks will bridge the gap. If now a gap is introduced in the circuit joining the outer coats of the jars, sparks will bridge this gap also in synchronism with the others. If the patient is included in this circuit he will experience strong muscular contractions, with little or no pain. To apply this current to the patient the insulating platform is not required. Two electrodes are needed, of the same kind as those used for the static wave current. They are applied to the body, the sliding rods are placed in contact and the machine is started. The sliding rods are cautiously drawn apart till the muscular contraction is as strong as the patient can bear.

The static induced current has been applied with

success to cases of obstinate constipation. One electrode is introduced per rectum (an electrode like that used with the static wave current may be employed). The other, a plain metal sheet, is placed on the abdominal wall. The current is started and its strength increased as far as the patient can tolerate.

When static treatment is being administered in the ways described and the operator has not a machine of sufficient power, better results can be obtained by attaching two small Leyden jars to the prime conductors in the way described for the static induced current, the outer coats are connected, one to the insulating platform, the other to the electrode.

CHAPTER XIV

INDEX OF ELECTRICAL TREATMENT

In the following pages are considered the maladies and morbid conditions for which electrical treatment may be applied. If the best results are to be obtained the general treatment should not be brought to a close when the electrical treatment is instituted, especially in those maladies in which electricity is applied in order to treat one or more symptoms of the general disease. In local conditions, too, better results are frequently obtained by combining the electrical treatment with the local treatment previously prescribed.

Acne Vulgaris.—Electrical treatment is sometimes successful in cases of acne vulgaris that have proved refractory to other methods. High-frequency treatment should be applied, using a vacuum electrode and moving it over the affected area. An erythema is produced and the ozone and nitrous and nitric acids formed possibly have some disinfectant action on the infected sebaceous glands. The treatment should be repeated twice or thrice weekly and each session should last about fifteen minutes. Diathermy may be tried, also using the vacuum electrode. The latter is kept in contact with the skin and moved about over the surface. It is connected to one pole of the diathermy machine, while the other is connected to a metal handle electrode grasped by the patient.

Ionisation with salicylic ions has been recommended, its action being probably a disinfection of the sebaceous glands

Acroparæsthesia.—This may be treated by application of rhythmically varying sinusoidal or faradic currents in an arm bath. Slow improvement commonly results.

Alopecia Areata.—Electrical treatment for this condition is sometimes required. Ionisation with copper or zinc should be tried first. A week later high-frequency spark discharges from a vacuum electrode should be administered.

Amenorrhœa.—The static breeze is very effective in restoring regularity of menstruation in cases of amenorrhœa and irregularity due to general debility. It is necessary, before applying this treatment, to exclude disease of the pelvic organs as a possible cause of the amenorrhœa. The patient is placed on the insulating platform and charged positively, while the negative breeze is directed against the spine and lumbar region. The treatment should be repeated daily or every other day.

Anal Fissure.—Zinc ionisation is an excellent treatment for this. A zinc rod wrapped in wool soaked in zinc sulphate solution is placed in the fissure and a current of 15 milliamperes is passed for twelve minutes. After a week the fissure heals or becomes much smaller. A second application may be made, if, at the end of the second week, the fissure has not healed.

Aneurysm.—Electrical treatment of aneurysms has been reserved for those for which surgical methods were without avail, but at the present time it seems to be rarely employed. The usual plan adopted was to insert two needles through the wall of the sac and pass a constant current between them. Coagulation would then take place around the needles as a result of the formation of acids and alkalies. This method of treatment has not

succeeded in bringing about anything more than temporary delay in the expansion of the sac. Puncture of the sac is not unattended by danger from hæmorrhage.

Aphonia.—Hysterical aphonia may be treated by applying the faradic current to the larynx. An active electrode provided with a closing key and carrying a chamois-leather-covered button is applied to the front of the neck over the larynx. The indifferent electrode is placed on the back of the neck. The current is passed for short periods with intermittent periods of rest.

Another method of treatment is to apply the static wave current to the front of the neck. Or static sparks may be administered to the same region.

Arthritis.—(1) *Injuries to Joints—Sprains.*—Such cases respond well and quickly to treatment by the galvanic current. Electrodes of the type used for ionisation and described on page 77 should be used. They should be soaked in salt solution. One is applied to the joint so as to envelop it as completely as possible. It is connected to the negative pole of the source of current. The other is applied to some other part of the limb. If there is much pain and tenderness, the electrode around the joint may be soaked, not in salt solution, but in sodium salicylate. Salicylic ions will then migrate through the skin and diminish the pain. The treatment should be given daily in the acute cases, twenty minutes each session. Chronic cases may receive the treatment on alternate days.

Joints that are stiffened by fibrous adhesions resulting from past injury can be rendered mobile by ionisation with the chlorine ion. The process is slow, but the treatment is effective. It should be applied in the way just described and repeated twice or thrice weekly.

Similar results can be obtained if the adhesions are due

to old inflammation, provided that the cause responsible for the inflammation is no longer present.

(2) *Gouty Arthritis.*—Cases of acute gouty arthritis do not come under electrical treatment. For the chronic cases ionisation with salicylic ions produces good results. If more than one joint has to be treated, the electrode connected to the positive pole can be soaked in a solution of a lithium salt and applied to another joint. The lithium ions are not more effective than the salicylic.

(3) *Gonorrhœal Arthritis.*—Good results have been reported in the treatment of the acute form by salicylic ionisation. For the sub-acute and chronic cases the same treatment is of value. Diathermy seems to be a valuable method of treatment of gonorrhœal arthritis; this is in accordance with the writer's experience. The rise of temperature through the joint possibly acts as a depressant on the vitality of the gonococcus. The adhesions that are left in a joint after gonococcal infection can be successfully treated by chlorine ions if the organism is extinct (see treatment of stiff joints under "Injuries to Joints").

(4) *Rheumatoid Arthritis.*—There is no known form of electrical treatment that is a cure for rheumatoid or osteo-arthritis. In the intervals between acute attacks some good may be done by ionising the joints with salicylic or iodine or lithium ions or by diathermy, but exacerbations are likely to occur, even during the course of treatment, if the cause responsible for the disease in any particular case (such, *e.g.*, as a septic focus) is not discovered and removed. If this can be done, electrical treatment, diathermy or ionisation (with salicylic or chlorine ions) is of value in promoting the absorption of effusion and the resolution of scar tissue and return of mobility.

Some cases of rheumatoid arthritis are benefited temporarily by the sinusoidal current, rhythmically

varied in strength, applied in a Schnee bath or in a full-length bath.

(5) *Osteo-Arthritis* (see under "Rheumatoid Arthritis").

Anterior Poliomyelitis (*Infantile Palsy*).—In this disease there are, for treatment, the spinal cord, motor nerves, muscles and the other tissues of the limb, including the skin. In the affected region of the spinal cord there are, in the first place, anterior horn cells that have been actually destroyed by the disease. The motor fibres arising from them and the muscle fibres supplied will degenerate and will ultimately be replaced by fibrous tissue and no treatment has any effect upon them. In the second place, there are anterior horn cells that have been damaged to varying degrees but not destroyed. Many of these will recover under appropriate treatment, and the muscle fibres that have been put out of action will be kept, by suitable treatment, in a condition of good nutrition, during the period while the nerve cells and their axons are returning to their normal condition. In the third place, there are frequently undamaged muscle fibres among others that have been injured; this is especially the case in the lower limb, where the muscles are supplied from anterior horn cells lying at different levels in the cord. Electrical treatment will stimulate these and cause their hypertrophy. In the fourth place, there are the other tissues of the limbs that are impoverished from poor blood supply, that results if many muscles are out of action. The skin becomes cyanosed and chilblains and ulcers often develop. Suitably applied electrical treatment will benefit all these conditions by its power of producing general stimulation of the dormant tissues and improving their blood supply. The improvement is first seen in the skin. Cold blue skin that has not responded to other treatment, also chilblains and trophic ulcers, begin to disappear as soon as the electrical treatment is started.

Electrical treatment is most effectively carried out by applying rhythmically varying sinusoidal current in baths. The details are described in Chapter IX., dealing with the treatment of paralysis. Under this treatment the blueness of the skin and the chilblains and ulcers rapidly disappear. The recovery of voluntary power in those muscles of which the motor cells and nerves have not been destroyed is a slower process, but good results will be obtained with perseverance, and the return of normal reactions to muscles which have shown RD, or have shown no response at all to electrical stimulation, is often observed. The best results of electrical treatment of infantile paralysis are seen in hospitals where the question of expense does not arise and cut short the treatment. At St Bartholomew's Hospital the mothers bring their children up regularly, month after month, and the good results that follow electrical treatment when properly applied with patience and perseverance, are seen. When applied in baths, using the rhythmically varied sinusoidal current, the amount of attention required is reduced to a minimum.

Asthma.—Static electrical treatment, in the form of simple charging, combined with the application of the roller electrode to the thorax, has produced good results in some cases.

Boils.—Small boils can be effectively treated by ionisation with zinc, a pad saturated in zinc sulphate solution being applied.

Carbuncles.—Leduc recommends their puncture to the base by a tenotome and the insertion into the channel of a zinc needle. This is connected to the positive pole of the source of current and a current of 30 milliamperes is applied for about thirty minutes.

Carcinoma (see "Malignant Growths").

Cardiac Failure.—In cases of impending death, electrical stimulation of the heart itself should not be attempted, as it is just as likely to cause the very thing we wish to prevent—that is, stoppage of the heart's action. It is best to use an induction coil with a long fine secondary wire, and metallic brush electrode to stimulate the surface of the body. This sets up a strong reflex stimulation of the heart and diaphragm by way of the vaso-motor and respiratory centres. The nose and upper lip are good points from which to influence respiration. If desired, the phrenic nerves in the neck may be directly stimulated and so set up contractions of the diaphragm. Two electrodes, each about one inch in diameter, are to be used. They are mounted on handles, and one of them is provided with a closing key. They are applied under the posterior border of the sterno-mastoid muscles, and the circuit closed and opened at intervals of about two seconds. This has been successfully employed in chloroform poisoning.

Chilblains.—These can be very effectively treated in arm baths or foot baths by the rhythmically varying sinusoidal current. For home treatment an induction coil may be used; its handles are placed in separate bowls of warm water, in which the hands or feet are immersed, one in each bowl. Some rhythmic variation can be produced by sliding the secondary over the primary or pulling the metal sleeve over the iron core. If the skin over the chilblain is not intact, it should be covered by a waterproof cloth, such as oiled silk or thin sheet rubber.

Chorea.—Static electrical treatment was formerly applied to this disease with excellent results. The child, supported by its mother on the insulating stool, is connected to one prime conductor. The other is connected to a ball electrode and sparks are directed along the spine

of the patient and the affected limbs. This method of treatment has fallen into disuse.

Colitis.—Ionisation with silver ions or with zinc ions has been recommended by Curtis Webb. As a result of this treatment the motions became natural in consistency and frequency, the mucus disappeared and the flatus diminished. (See page 85.)

Congestion.—The good results that follow the treatment of injuries in the region of joints, accompanied by swelling and effusion of fluid (see under "Arthritis—Injuries to Joints"), illustrate the influence of the constant current on congestion. The current may well be applied as an aid in the removal of inflammatory products after the agent responsible for the inflammation has been removed or has ceased to operate; the current also aids the absorption of fluid exudations. Thus in cases of crutch palsy the treatment should include the application of the constant current to the area in the region of the pressure, where there is likely to be congestion.

Constipation.—When this is due to atony of the muscular coats of the intestine, electricity is probably the most efficient method of treatment known. Large currents and large electrodes are to be used. If the constant current is to be employed the anode is the indifferent electrode and it is placed under the lumbar spine as the patient reclines. The kathode or active electrode is a padded metal disc about four inches in diameter. It is soaked in saline and applied with firm pressure over the front abdominal wall, moving it round rather slowly from the cæcum along the course of the colon to the sigmoid flexure, where it is allowed to rest from two to five minutes, when the process is repeated.

This should be done every other day for three or four weeks. A sinusoidal current of low frequency—from one

to two periods per second may be used if the constant current is ineffective. Or the constant current may be made to vary its strength rhythmically by including a rhythmic interrupter in the circuit.

Such treatment is frequently followed by gradual improvement and restoration of the normal frequency of defæcation that persists after the treatment is brought to a close.

In obstinate cases one of the electrodes should be placed in the rectum, the other on the abdominal wall. The rectal electrode consists of a metal tube enclosed, except at one end, in a loose membrane bag. This metal tube serves to conduct the current, and at the same time allow the introduction of saline into the membrane bag when the latter is placed in the rectum and so distend it that its walls come in contact with the rectal wall. The rhythmically interrupted or slow sinusoidal current is used for about ten minutes. It sometimes happens that the bowel is provoked to action before this time elapses. In all cases the ordinary rules for dealing with constipation must not be neglected—such as exercise, massage, suitable diet and use of laxatives until the case so far improves that the latter can be gradually reduced to vanishing-point.

The static wave current and static induced current should be tried in cases that resist other methods of treatment. (See pages 205-207 and 212.)

Corns.—The opinion has been expressed by Lewis Jones that *painful* corns are the result of an infection of an ordinary callosity by some micro-organism, the callosity being, when not infected, painless. The treatment recommended is ionisation with zinc. It is necessary, however, to make some preliminary preparation of the corn before the ionisation. The tough, thickened skin is dry and will not conduct a current. A compress

soaked in 1% zinc sulphate should be worn in contact with the corn for twelve hours beforehand. The thick skin will then be moistened and some ions will diffuse in and conduct the current. One application is often enough.

The patients will not always carry out the instructions to keep a moist compress in contact with the corn, and they sometimes arrive for treatment with the corn dry. If, then, an attempt is made to ionise it, no current will flow unless part of the pad comes in contact with the surrounding skin, in which case, all the current will pass in that way and no ions will penetrate the corn.

An alternative method is to apply salicylic acid and collodion for a few days beforehand and then ionise with salicylic ions after the thick skin has separated.

Another method, which the author has used with success in some cases where the corn is very thick and hard, is to cut away as much as possible of the epithelium and ionise with a solution of potassium iodide (1%), containing in solution iodine (1%). A wall is formed around the corn of some material, such as plasticine or modelling wax, for the purpose of holding the solution and preventing the entry of the current in any way other than through the corn. The chamber thus formed is filled with the solution. The conducting cord (from the negative pole) is fixed near it, say by a safety pin through the rubber tube covering and the cushion on which the foot lies. A fine flexible copper wire is wound round the bare metal end of the conducting cord. The free end of the flexible wire is laid across the top of the plasticine chamber and embedded in its wall, so as to make contact with the fluid inside. Good contact between the other end of the flexible wire and the conducting cord is secured by partly turning back the rubber covering of the latter and then replacing it over the flexible copper wire and so keeping the metal surfaces

in contact. The solution in the plasticine chamber may be held in place without fear of it running out by filling the latter with cotton wool before adding the fluid.

Corneal Ulcers.—Zinc ionisation is often successful in the treatment of "Mooren's ulcer." A tuft of cotton wool soaked in a 1% solution of zinc sulphate is wound round the end of a zinc rod, with its end free. The rod is connected to the conducting wire leading to the positive pole of the battery, and the free end of the tuft is placed on the ulcer, moving it slightly so as to come in contact with all parts of it. A current of 1 to 1½ milliamperes should be passed for four or five minutes. Cocaine should be applied to the eye before the treatment.

Corneal Opacities. — Considerable improvement in vision follows ionisation with chlorine ions. The lachrymal secretion contains sodium chloride in solution (and, therefore, chlorine ions), so if the lid is closed and the electrode, in the form of a lint pad soaked in salt solution, placed on the exterior and made the kathode, the passage of a current will cause the migration of the chlorine ions into the cornea. No anæsthetic is required. A current of 5 milliamperes may be borne, for two to four minutes.

Disorders of Digestion.—Electricity is useful in some disorders of the digestive tract. A slow sinusoidal current is most useful, one electrode being placed on the lower dorsal spine and the other over the epigastrium. It should be applied daily or at least three times a week for ten minutes. Dilatation of the stomach caused by atony of the wall has been successfully treated by this means.

Disseminated Sclerosis.—Electrical treatment is sometimes requested for this disease. It cannot be said that

any form of electrical treatment is of value. Temporary improvement, which is occasionally noticed, is not likely due to any form of treatment that the patient is happening to have at the time, as such improvement often occurs even when no treatment is given.

Dupuytren's Contraction.—Occasionally, though not as a rule, good results are obtained in the treatment of this condition of the palmar fascia by chlorine ions. Treatment should be continued for a month or six weeks before it can be seen whether any improvement is likely to take place.

Dysmenorrhœa.—Many cases of this condition are relieved by static electrical treatment. The patient is charged positively and the negative breeze is applied to the spine and loins. Lewis Jones recommends that the treatment should be given daily for a week or two before the onset of the period. With the commencement of the flow it should be left off and afterwards reapplied as before, prior to the onset of the next period.

Endometritis.—Sloan and other writers have obtained excellent results in the treatment of septic endometritis by zinc ionisation. A zinc sound is introduced into the uterus and connected to the positive pole of the source of current ; a current of 20 to 40 milliamperes is passed for fifteen minutes. If there is difficulty in withdrawing the sound at the end of the operation, the current, after reaching zero, should be reversed and allowed to flow in the opposite direction for a few minutes. Discharge follows for some days after the treatment and vaginal douches should be given. If it does not disappear after ten days the ionisation should be repeated.

Episcleritis.—This may be treated by ionisation with salicylic ions. A pad soaked in the solution of sodium salicylate is placed on the external aspect of the lid and

a current as strong as can be comfortably borne (5 to 10 milliamperes) is passed for ten minutes.

Exophthalmic Goitre.—Cardew recommended the use of the constant current passed through the thyroid gland from the lower cervical spine to the side of the neck. Currents from 2 to 3 milliamperes, for six minutes, to be applied three times daily.

Fibrositis.—Ionisation with iodine or salicylic ions is sometimes effective in relieving the pain associated with this condition.

Fissure (see **Anal Fissure**).

Fistula.—Some cases of rectal fistula successfully treated by zinc ions have been reported. Billinkin's method was to pass a zinc rod—its tip insulated by a cap of wax—into the fistula until the insulated end reached the inner end of the fistula. A current of 6 milliamperes was passed for three minutes. The process was repeated every two or three days, the zinc rod passed less far up the fistula each time. The fistula began to heal first at its upper end, and the healing process extended downwards till the whole length had healed.

Furuncle (see **Boil**).

Gouty Arthritis (see **Arthritis—Gout**).

Gonorrhœa.—Gonococcal urethritis has been successfully treated by ionisation with zinc or copper. W. J. Morton's method was to pass a sound with a brass stem, insulated, except at its free bulbous extremity, along the urethra up to the neck of the bladder. The current was then turned on and the stem was then slowly extracted, so that the ions from the bulbous end could pass into the wall of the urethra throughout its length. To one patient treated in this way one application only was

given, and he remained free from infection for a year, when he then acquired it again.

Fenwick successfully treated two cases of long-standing chronic urethritis by zinc ions. A zinc rod was covered with lint and soaked in 2% zinc sulphate solution. It was inserted into the previously cleansed urethra, through a cannula, which was afterwards withdrawn. Small currents were used, 2 to 5 milliamperes.

Hæmorrhoids (see **Piles**).

Headache.—Headache that is associated with *low* blood pressure is best treated by the static breeze applied to the scalp, the body being positively charged. The pain often disappears during the first treatment, a result, most probably, of the rise of blood pressure. Headache associated with high blood pressure may be treated by general diathermy, the endeavour being to lower the pressure. For the description of the method of application see under **High Blood Pressure.**

Hemiplegia.—Cases of paralysis that are due to lesions of the upper motor neuron will benefit if the cause responsible has disappeared or is no longer active. If, however, there is late rigidity, much cannot be expected from electric treatment. The treatment is suitable for cases of hemiplegia due to cerebral hæmorrhage. It should begin a fortnight or three weeks after the hæmorrhage and be continued, three times weekly, for a month. If improvement occurs the treatment may be continued for further periods of one month each, till no further benefit is noticed. The treatment is best given in a full-length bath (rhythmic sinusoidal current) if the lower limbs are affected. The Schnee bath may be used when no full-length bath is available, and it can be used when the paralysis affects either the lower or the upper limbs.

Leduc recommends that treatment should be given to

the lesion when present in the brain, by passing the constant current through it from the back of the neck (anode) to the forehead (kathode). The treatment should be given daily, or on alternate days, and for fifteen minutes, with a current of 20 milliamperes.

High Blood Pressure.—Some writers have obtained a lowering of high blood pressure by means of general applications of high frequency, given on the auto-condensation couch; others have been unsuccessful, although the same method was used. Possibly the condition of the arteries, whether in an advanced state of sclerosis, or in the pre-sclerotic condition, may be the factor which determines the effect of high-frequency applications.

To carry out the treatment the patient should be on the auto-condensation couch and the current applied daily for about a week or ten days. The blood pressure should be measured after each treatment, and if it sinks during an application a watch should be kept for symptoms of syncope, and if there is a feeling of faintness the treatment should be stopped, and resumed the following day.

Nagelschmidt speaks highly of diathermy as a means of lowering high blood pressure. One electrode is placed on the precordium, the other on the back of the chest. Applications not longer than five minutes at the commencement. They may be lengthened later. The blood pressure should be estimated before and after each treatment.

Hypertrichosis.—Superfluous hairs may be removed by means of the electrical current. It has been mentioned that the passage of the constant current through the tissues is accompanied by the formation of caustic soda and hydrogen at the kathode. If the kathode is a fine platinum wire and is introduced into the hair follicle the caustic soda will destroy the follicle and the hair can be

lifted out. The operation causes a stinging pain, but not greater than the patient can bear.

A local anæsthetic should not be applied. The details of the operation are described on page 89. After each hair is removed a small zone of hyperæmia is left round each follicle and sometimes œdema. These soon disappear, and if the operation is neatly done, with a small current (not more than 2 milliamperes) and short applications, no scar will remain. If a group of hairs in close proximity is removed at one sitting it is likely that a scar will be left. A small proportion of hairs will return, because it is not possible to ensure entire destruction of the follicle without strong currents. The hairs that return can always be treated again when they reach a sufficient size.

The operator must always warn the patient of the likelihood of the return of a small number of hairs.

Hysteria.—The most useful rôle of electricity in hysteria is for the removal of paralysis, anæsthesia and spasm (Lewis Jones). The current from the induction coil, applied by the ordinary moistened electrodes, or by the wire brush, may be used. Sparks from a static machine are effective and have an additional psychic effect. For the general hysterical condition, apart from local symptoms, the long bath with sinusoidal currents, or the static breeze, may be used.

Incontinence of Urine.—The cases of incontinence of urine for which electrical treatment may be given with prospect of success are those due to weakness of the sphincter, and those in which the incontinence is really an unconscious act of micturition occurring during sleep. Incontinence resulting from weakness of the sphincter occurs in female patients and does well under electrical treatment. The rhythmically varying faradic current is used. One electrode is a metal sound. It is placed in

the urethra without passing into the bladder. The other electrode is a padded metal plate and is placed on the spine in the lower dorsal region so as to overlie the lumbar enlargement of the spinal cord. Treatment may be given daily for periods of ten or fifteen minutes and less frequently as improvement proceeds.

For cases of nocturnal micturition during sleep the same treatment may be given when the patient is a female. In male patients one electrode is placed on the lower dorsal spine, the other on the perinæum. A special electrode is used for applying to the perinæum (Fig 61). It is composed of a wooden handle bearing

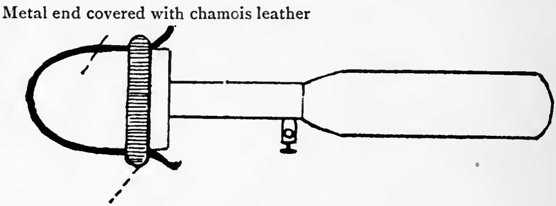


Fig. 61.—Electrode for Enuresis (seen in section)

a cone-shaped metal end-piece with rounded apex. The latter is covered by chamois leather secured in position by a vulcanite ring which slides over the cone and fits tightly around its base. Stroking movements of the leather-covered end of the electrode are made over the perinæum and so produce the rhythmic variation. For cases of nocturnal micturition during sleep stronger applications are necessary, so as to produce a strong sensory impression on the urethra, and so on the cerebral sensory centres. In this way the patient is made more strongly aware of the condition of the urethra, so that when the bladder is about to expel its contents into this channel the cerebral centres receive stronger impressions and the patient is awakened. Lewis Jones recommended the application of the galvanic current after the faradic

for three or four minutes, with reversals of direction every five seconds, and of a strength of 5 to 10 milliamperes.

Cases of incontinence that are due to irritability of the bladder wall do not benefit under electrical treatment. The irritability is due to inflammation of the bladder wall and the incontinence will persist until the cystitis is removed.

Ingrowing Eyelashes.—These can be removed by electrolysis (see under **Hypertrichosis**), but the operation is painful, on account of the sensitiveness of the part. Many of the hairs are fine and difficult to remove.

Insomnia.—Electrical treatment is occasionally given for insomnia, in conjunction with other methods of treatment. Patients whose blood pressure is low are best treated by the static breeze ; those in whom it is high should receive general high frequency or general diathermy.

Intermittent Claudication.—Electrical treatment in a Schnee bath, with rhythmically and slowly varying faradic or galvanic currents, may be applied in these cases. Good results are obtained, but courses of treatment should be repeated periodically.

Joints, Injuries and Diseases (see under **Arthritis**).

Keratitis.—Traquair recommends the use of zinc ions for the treatment of purulent keratitis and has obtained good results by this method. He devised a special electrode for the purpose. It consists of a zinc rod with a celluloid cap at its end. The cap is filled with cotton wool soaked in $\frac{1}{2}$% zinc sulphate solution. The wool is brought into contact with the ulcer and stroked over it.

Lachrymal Obstruction.—Obstruction of the canaliculi can be removed by inserting a platinum probe into the

canaliculus; an indifferent electrode is placed in some convenient situation; a constant current, 2 to 4 milliamperes, is passed from the indifferent electrode to the platinum probe for thirty seconds. The probe is therefore the kathode. Two or three sittings are required. The obstruction is permanently removed (Jessop and Steavenson).

Locomotor Ataxy.—Some of the symptoms of this disease can be relieved by the application of the constant current to the spine. One electrode (the anode) is applied to the cervical spine, the other to the lumbar spine. The pains and unsteadiness of the gait are relieved in many cases. The same treatment is recommended for the crises—gastric, laryngeal and vesical. It is said that if it is applied during a crisis the pain is relieved in a few minutes.

Lupus Vulgaris.—Of the electrical methods of treatment of lupus vulgaris two may be mentioned: (1) Ionisation with zinc ions. This method gives good results in cases where nodules persist after healing of ulceration by Finsen light or X-rays. The method recommended by Taylor and MacKenna is to first rub the part with liquor potassæ. This denudes the nodules of their epithelium. The liquor potassæ is washed away with water and the part of the skin containing the nodules is covered with a lint pad saturated with 2% zinc chloride solution, or 10% zinc sulphate. The current is passed for ten to thirty minutes. The ionised part gradually becomes swollen and red, and a crust forms on the surface. A fortnight after the ionisation the crust drops off and the nodules are then seen to have become smaller. Some may have disappeared. So long as any nodules remain the treatment is repeated fortnightly. A smooth elastic scar results. (2) "Reyn's electrolysis." The patient takes, by mouth,

a large dose (40 to 60 gr.) of potassium iodide. An hour later the lupus nodules are transfixed with a group of platinum or iridium needles set close together on a suitable handle. A current of 3 to 4 milliamperes is passed from the needles (the anode) through the nodule and to an indifferent electrode for three minutes. The needles are then taken out and reinserted in a different position and the current again passed for a similar time. The process is repeated till the nodule has been transfixed in all directions. Iodine is set free around the needles and destroys bacilli in the neighbourhood. The following events occur during the process. The potassium iodide is absorbed and passes into the tissue fluids. The latter, therefore, contain iodine ions. Those present in the lupus nodule are attracted to the needles (which form the anode). They give up their electric charge and then become free iodine.

The treatment is repeated daily until the nodule has disappeared.

No necrosis of the tissue takes place.

This method of treatment is suitable for lupus of the mucous membranes.

Malignant Growths.—Malignant tissue can be destroyed by means of zinc ions, using very strong currents and long applications, under general anæsthesia. Several applications are necessary. Betton Massey is the advocate of this method. It is described on page 97. Keating-Hart uses the sparks from powerful high-frequency apparatus. "Fulguration" is the name given to this form of treatment. The destruction caused by "fulguration" is most probably due to heat.

The most successful method of treatment of inoperable growths is by diathermy. For particulars see page 190.

Menstrual Irregularities (see **Amenorrhœa** and **Dysmenorrhœa**).

Mental Diseases.—The cases most likely to benefit are those of melancholia in adolescents and mental apathy. These are often accompanied by failure of general nutrition. In the cases reported the method employed was a course of sinusoidal baths, and the results were so good that it should be always tried. The general effects were a complete, or nearly complete, relief of mental symptoms and a progressive gain in weight. Apparently these good results were due to the improvement in general nutrition—the brain benefiting indirectly.

Meralgia Paræsthetica.—This is a painful numbness of the outer aspect of the thigh. It is due to a neuritis of the external cutaneous nerve caused by injury or pressure. Pressure by a badly fitting corset may cause it. Ionisation with salicylic ions is a suitable form of electrical treatment.

Metatarsalgia.—The author has seen good results, in two cases of metatarsalgia, follow the heating through of the feet by diathermy. One patient on which surgical operation had been repeated, without lasting benefit, improved so much that he was able, after a course of treatment, to walk long distances without pain.

Moles.—Small hairy moles should be treated by removing the hairs, using the method described under **Hypertrichosis.** The mole will then disappear. If there is a pigmentation of the skin much of it will disappear after the epilation. If there is much remaining pigment it can be removed by destroying the cells in which it lies by means of zinc ions. A zinc needle is inserted at several points for short distances and currents of 2 milliamperes passed for one minute for each insertion.

Moles without hair can be treated by ionising their base with zinc, using a zinc needle. The method is described under **Warts.**

Monoplegic (see **Hemiplegia**).

Myalgia.—By this is meant muscular pain—the result of over-fatigue—a condition which is brought about very easily in debilitated persons. It is most frequent in the trunk muscles and is accompanied by local tenderness and increase of the pain on movement. It is found, most usually, at the origin or insertion of certain muscles, the most common of which are the trapezius, spinal muscles, pectoralis major and minor (inframammary pain) and rectus abdominis.

General electrical treatment, by rhythmic sinusoidal currents, in the long bath is of value in improving the condition of the body and the muscles. Local applications of the same current are useful for the treatment of the affected muscles only. The constant current, without rhythmic variation, may also be tried ; the anode being placed over the painful area.

Myelitis.—Electrical treatment is beneficial for the *results* of myelitis—*e.g.* weakness in the lower limbs and in the bladder and rectum—and for trophic alterations in the skin—*e.g.* bed-sores.

The constant current should be applied to the spine ; the electrodes should be placed over the vertebral column so as to include between them the damaged spinal cord. The application of rhythmically varied faradic or sinusoidal currents in baths is useful in improving the condition of the muscles of the limbs. Bed-sores should be treated by zinc ions.

Nævus.—The method of destruction of nævi by electrolysis (described in detail on page 91) has an advantage in that it destroys very little of the skin if skilfully applied. This makes the method particularly valuable when the nævus is wholly or chiefly under the skin, and when it is situated on the face or other parts

exposed to view. An anæsthetic is required and more than one treatment is necessary, unless the nævus is very small. The method of treatment by carbon dioxide snow was largely used for treatment of nævi, but, in the writer's experience, is less satisfactory than electrolysis in the case of nævi on the face and scalp. During treatment by solid carbon dioxide it is very difficult to completely destroy the nævus, unless the application is long enough to cause destruction of the skin in the region as well as the part of underlying tissue.

Neuralgia.—It is necessary, when using the term neuralgia, to have a clear knowledge of what the term connotes. The term should be used for those cases of pain in the area of distribution of a nerve without any morbid condition of that nerve. The pain is a "referred pain," referred to the area of skin supplied by the nerve. There may be an evident exciting cause.

When present, it is not on the same nerve or nerve branch along which the pain is referred, but on another, so that the reference of the pain is a sort of reflex act, the afferent and efferent channels being sensory nerves. Thus a carious tooth may be a source of irritation of the inferior dental branch of the fifth nerve and cause a pain to be referred reflexly along the cutaneous branches of the trigeminal nerve. Neuralgic pains are frequently intermittent pains. Cutaneous tenderness is frequently present. A form of electrical treatment that is suitable for neuralgia (referred pains) is the application of the faradic current by means of a wire brush to the skin, so as to produce strong counter-irritation. Another method of treatment is the introduction of ions into the skin. Exciting causes must be looked for and removed, if possible. Often there is no discoverable cause.

(1) *Trigeminal Neuralgia.*—Some cases of trigeminal

neuralgia benefit greatly by introducing, into the painful area of skin, salicylic ions or quinine ions. The affected side of the face should be covered by a well-fitting pad.

(2) *Great Occipital Neuralgia.*—Neuralgia of the great occipital nerve should be treated by ionisation with salicylic or quinine ions.

Neurasthenia.—This is a term applied to a class of case which is characterised by a sort of nerve exhaustion or "nervous debility"—the patients considering themselves mentally and physically worn out, as well as the subject of some serious organic disease. They are convinced of their own inability to discharge the "daily round," and in neglecting their usual vocation give themselves up to brooding over and magnifying their real or fancied disabilities.

In the treatment of neurasthenia we should, as far as possible, endeavour to improve the moral or mental condition of the patients by encouraging them to feel more confidence in themselves and to assure them that recovery is within their reach. In most cases it is advisable for them to give up their usual vocation for a time, which may be anything from three months to a year, or even more. Complete rest with change of diet and environment are very important factors in bringing about a cure.

Electrical treatment may be prescribed as part of the general conduct of a case of neurasthenia. General stimulation of the body, by means of the sinusoidal current in baths is useful. The form of general stimulation of the nerve centre known as "central galvanisation" should be tried.

Neuritis.—Electrical treatment is of value for cases of neuritis. The way in which it should be applied depends upon the degree of pain present. In some cases of neuritis the motor nerves are mainly affected and

paralysis is the chief symptom. In others the sensory nerves are chiefly involved and pain is the chief symptom. In neuritis accompanied by pain, the pain may be localised to the nerve trunk, or it may be felt in the region supplied by the fibres. In the former case the inflammation affects the nervi nervorum ; in the latter it affects the sensory fibres contained in the main trunk and its branches.

Where paralysis without pain is the chief feature, the rhythmically varying current should be applied, the electrodes being arranged in positions so that the affected nerves and their muscles are included in the treatment. The current may be applied to the part placed in a bath. The treatment is best given in full-length baths when the neuritis is general. The details of the method of electrical treatment are described in the chapter on the treatment of paralysis.

When pain is the chief symptom of the neuritis, it should be treated by ionisation with salicylic or quinine ions. Applications of diathermy, so as to heat through the painful part, should be tried. The application of gentle rhythmic sinusoidal current in baths is also beneficial.

When the neuritis is due to a general cause the best plan is to give the treatment to the whole body, even if only one nerve trunk is affected. The general treatment is likely to promote elimination of the toxins, and, in addition, stimulates the self-defensive action of the body.

(1) *Alcoholic Neuritis.*—Electrical treatment is not prescribed in the acute stage of this form of neuritis when there is pain, but when this stage has passed and the patient is left with weakened or powerless muscles, treatment in the full-length electrical bath with rhythmically varying sinusoidal or faradic currents is of value and hastens recovery.

(2) *Arsenical Neuritis.*—Neuritis may be the sequel

of a single large dose of arsenic, and it arises when the violent acute symptoms that immediately follow the dose have subsided. Neuritis may also arise during the medicinal application of increasing doses of arsenic, with or without general symptoms (salivation, nausea, vomiting, etc.). Electrical treatment may be given, with benefit, when the acute stage has passed, on the lines already laid down.

(3) *Brachial Neuritis.*—This is a neuritis that involves the brachial plexus, either the whole or one or more of its trunks. It occurs after injury or exposure to cold, in patients who are predisposed to it by gout, alcohol or syphilis. The latter maladies should receive appropriate treatment and electricity should be applied in the form of diathermy or ionisation when there is pain. If there is weakness afterwards, rhythmic sinusoidal or faradic currents should be applied.

(4) *Rheumatic Neuritis.*—This is a clinical form of neuritis in which there is no evident cause ; a history of exposure to cold and wet is sometimes obtained, but this is most probably a predisposing cause. Brachial neuritis is, in many cases, a "rheumatic" form of neuritis ; so also is sciatica. Facial palsy is frequently the result of a "rheumatic" form of neuritis.

The form of electrical treatment is determined by the degree of pain present, ionisation if there is much pain, sinusoidal currents if there is, chiefly, weakness.

(5) *Septic Neuritis.*—This is a form of neuritis that occurs in parts that are the seats of septic infection. The exciting cause is no doubt the infecting organism. It is seen in cases of bullet and shrapnel wounds that have become infected, and it sometimes occurs in parts that have been the seat of abscesses. It seems possible that toxins absorbed from septic foci may cause neuritis in parts at a distance. Lewis Jones mentioned a case in which facial paralysis, accompanied by pain

and numbness on the same side of the face, followed confinement attended by sepsis.

Recovery in cases of septic neuritis is very slow.

Lewis Jones recommended the use of the constant current in the limb baths. The cases that have been sent to the writer for treatment of septic neuritis in soldiers following bullet and shrapnel wounds have derived benefit from the constant current, applied through moistened pads or in the Schnee bath.

Neuritis may occur after many of the specific fevers. General electrical treatment in baths is useful in such cases. Neuritis is liable to occur in syphilis, the poison of the latter being especially prone to attack nerve tissue. Electrical treatment should be given in conjunction with anti-syphilitic remedies. Neuritis may also occur after gonococcal infection.

Nocturnal Incontinence (see **Incontinence**).

Obesity.—Bergonié has introduced a new electrical method for the removal of superfluous fat. A faradic current is used to rhythmically tetanise the limb and trunk muscles and make them work against resistance. The current from a specially designed induction coil is taken through a mercury metronome in which it is interrupted about sixty times each minute. It is then distributed to separate pairs of electrodes, which are applied to the body and include between them different groups of muscles. The strength of current passing to each pair of electrodes is regulated by a variable resistance. The resistances are mounted on a switch-board. Of the electrodes, four are metal plates fixed to a special reclining chair, two to the back, two to the seat. They are covered, each separately, with towels soaked in hot water. When the patient sits on the chair his shoulders and back are in contact with two of these electrodes, his buttocks and thighs with the other two. His legs and forearms are

suitably supported on rests. Other electrodes are made of metal plates. They are applied to the forearms, abdomen, thighs and legs, with pads of moistened lint intervening, and secured in position by straps. When the apparatus is set in action the various muscle groups contract rhythmically and simultaneously, sixty times each minute. The movements of the limbs and other parts are resisted by sand-bags placed on the abdomen and front of legs, thighs and forearms. The total weight of these bags may reach 100 lb. or more. As a result of the large amount of work passively done by the muscles, the patient sweats profusely and gives off large quantities of heat, and excess of carbon-dioxide is exhaled. The pulse-rate increases and the blood pressure falls.

Treatment should be given daily, for periods of twenty minutes at first, afterwards increasing the sessions to thirty minutes or more. A loss of weight of three to five pounds a week may be expected. A large appetite may arise as the weight diminishes and must be controlled.

Occupation Spasm (see **Writer's Cramp**).

Œsophageal Spasm.—This condition of muscular spasm of the œsophagus without organic stricture may be treated by passing the faradic or galvanic current between electrodes placed, one on the spine over the œsophagus and the other on the front of the chest.

Œsophageal Stricture (see Chapter VI., page 96).

Orchitis and Epididymitis have been successfully treated with the constant current with the electrodes placed on the front and back of the scrotum. In the acute stage but very mild currents can be borne—$\frac{1}{2}$ to 1 milliampere. In the chronic stage 10 or 20 milliamperes may be employed. The electrodes may be moistened with potassium iodide solution, and then the iodine ions

which migrate in from the negative electrode may have some therapeutic action.

Ophthalmia Neonatorum.—A case treated by zinc ions was reported by Ramsden. A cotton-wool pad soaked in a 2% solution of zinc sulphate was placed on the front of the cornea and sclerotic. A current of 0·5 milliampere was passed for three minutes. The treatment was repeated twelve hours later. In two days the ophthalmia was cured.

Optic Neuritis.—Cases have been reported in which improvement has resulted by passing the constant current transversely from temple to temple and longitudinally between the front of the eye and the back of the head. Small currents are used—2 milliamperes.

Ovarian Neuralgia.—This may be treated by passing the constant current between the front of the abdomen where the pain is felt and the back. Large currents, of 40 to 50 milliamperes, should be used.

Ozæna.—High-frequency treatment with a vacuum electrode introduced into the nasal cavity has been recommended and good results have been reported. Ionisation with copper ions has produced good results. The cavity on each side is packed with cotton-wool soaked in 2% copper sulphate solution, and a copper wire is embedded in the wool without touching the mucous membrane anywhere. Currents as strong as can be borne by the patient without pain should be applied for fifteen minutes.

Paralysis.—The electrical treatment of paralysis is considered in Chapter IX.

Paralysis Agitans.—The writer has seen considerable improvement in three cases of this disease following general diathermy. In two patients, electrodes were

grasped by the hand ; in the third the treatment was applied on the Schittenhelm condenser couch. The tremors diminished and the gait improved and there was a gain in general health. The improvement was maintained for some weeks after the treatment was left off, but ultimately the symptoms recurred. Treatment was given for periods of twenty to thirty minutes, twice weekly.

Paraplegia (see **Hemiplegia**).

Perineuritis.—This is an inflammation of the sheath and interstitial connective tissue of a nerve trunk. The pain is probably due to irritation of the nervi nervorum—*i.e.* the nerve fibres that supply the sheath and connective tissue. The electrical treatment should take the form of diathermy, or ionisation with quinine or salicylic ions, as mentioned under **Neuritis.**

Piles may be treated by zinc ionisation. A method was described by Bokenham (*Proc. Roy. Soc. Med.*, vol. ii., section of Electro-therapeutics, page 135). The pile is transfixed with a zinc needle previously amalgamated by dipping it for a moment first in water, then in dilute sulphuric acid, then in mercury. The needle is connected to the positive pole. An indifferent electrode is placed under the hip, the patient lying on his side. The current is very slowly increased, till, after ten minutes, it reaches 25 milliamperes. The pile changes in colour from a red or blue-red to a yellow or grey-yellow. Then the current is diminished, with equal slowness, to zero. Before the pile is transfixed, 10% cocaine is applied on a pad, and then cocaine (5%) and adrenalin are injected. After ionising one portion there should be an interval of ten days.

Pleurisy.—Pleural adhesions may be treated by chlorine ions (Leduc). Large electrodes are used, placed

on each side of the chest, and one should be of sufficient size to cover nearly the whole of the affected side. The other should be placed on the other side. Strong currents should be applied for long sittings and frequently repeated.

Port-Wine Marks.—These may be treated by the method of surgical ionisation, described in Chapter VI., under **Nævi**. They may also be treated by high-frequency sparks directed on to the surface of the overlying skin from a metal point electrode connected to the solenoid. Erythema and vesication follow, and obliteration of the port-wine mark frequently follows.

Prostatic Enlargement.—The static wave current has been recommended for enlargement of the prostate, but only when the enlargement is due to congestion. A special electrode is used and is placed in the rectum in apposition with the prostate. See page 207.

High-frequency treatment on the condenser couch with a metal electrode in the rectum has been recommended.

Pruritus of the anus and vulva may be treated successfully in some cases by the static breeze, or by the high-frequency effluve. The glass vacuum electrode may be used either with the high-frequency or the diathermy machine.

In some cases iodine ions are successful. A 2% solution of potassium iodide is used. A circular aperture is cut in a piece of waterproof cloth and applied to the skin between the buttocks, so that only the affected part around the anus is exposed. A lint pad soaked in the solution may then be applied over the aperture. In this way iodine ions will gain entry only into the part desired.

Pyorrhœa Alveolaris.—This may be treated by zinc ions. A zinc needle with a thin layer of wool wrapped round it, soaked in 2% zinc sulphate solution, is insinuated between the gum and the root of the tooth. Only a very small current can be borne, $\frac{1}{2}$ to 1 milliampere. On subsequent applications it may be strengthened. The current is passed from a half to one minute. The current must be increased very gradually and evenly, on account of the tenderness of the part. When the current is derived from a portable battery of cells a shunt resistance must be used, so that the current that is to be applied to the teeth can be gradually and evenly regulated.

Raynaud's Disease.—Electrical treatment does not prevent the onset of the paroxysms of this disease, but if the affected limbs are immersed in a bath and subjected to the galvanic current during a paroxysm it is said that the duration of the attack is lessened.

Rectal Fistula (see **Fistula**).

Rheumatoid Arthritis (see **Arthritis**).

Rickets.—Children suffering from rickets are not usually sent for electrical treatment, but improvement quickly follows the general stimulation of the body provided by the rhythmic sinusoidal current in the electric bath. Lewis Jones spoke highly of this method of treatment.

Rodent Ulcer.—This may be treated by ionisation with zinc ions, and the method is more particularly indicated in the early cases. The surface of the ulcer is cleaned with a 2% solution of zinc sulphate after removing any crusts or discharge. A pad of lint, cut to fit the ulcer and slightly overlapping its edges, is applied to it. A zinc disc, bearing a terminal for the conducting

wire, is pressed against the pad. The current is passed for fifteen minutes. It is very gradually increased till it is as strong as the patient can bear. The tissue underlying the pad becomes pearly white. The treatment need not be repeated till fourteen days have elapsed, and only if the ulcer fails to fill up.

For chronic rodent ulcers and ulcers that have developed again after they have healed under former treatment, diathermic cautery is recommended. The writer has seen one case of rodent ulcer that proved to be intractable to all other methods of treatment heal under the influence of diathermic cautery. He has also treated one case of rodent ulcer in the pre-ulcerative condition, by diathermic cautery under local anæsthesia. The growth sloughed away and, six months later, had not recurred. It is too early yet to speak of the permanence of the results obtained by diathermic cautery. The method should receive further trial. For details of the method see Chapter XII., under **Surgical Diathermy.**

Sarcoma (see **Malignant Growths**).

Scars.—The scar tissue that is formed after chronic-inflammatory processes can be softened and rendered less tense by ionisation with chlorine ions, provided the cause responsible for it is no longer present. Adhesions in joints can be loosened in this way. The writer has seen the cicatricial contraction that followed a Halsted operation and prevented abduction of the arm disappear after twelve sessions of ionisation with chlorine ions and full-range movement of the arm return. After destruction of tissue—*e.g.* by burns—the scar tissue that forms can be rendered soft and supple. Good cosmetic results follow after treatment of scars following burns by this method. It is necessary to be patient. If treatment is given thrice or twice weekly, six or eight weeks must not be considered a long period.

Sciatica.—Electrical treatment of sciatica is not likely to be successful if, from improper or neglected treatment in the early stages, scar tissue has formed in the sheath and perineural connective tissue and has compressed the nerve fibres. It is most likely to be beneficial when the nerve trunk is in an earlier stage and organic changes have not taken place. After the early acute stage has passed the electrical treatment may take one of three forms. Ionisation with quinine ions or salicylic ions may be tried. The pads must be large. One, four inches wide, should be placed on the back of the thigh and extend from the back of the knee to the sacrum. The other, of a similar size, should be placed on the front of the thigh and abdomen.

Diathermy may be tried. Nagelschmidt recommends the following method. A small electrode is placed over the nerve in regions that are tender on pressure. The indifferent electrode is placed on the opposite side of the limb. A current of $\frac{1}{2}$ to 1 ampere is passed for five minutes, so as to heat the nerve without burning the skin. Other tender regions are heated in the same way, each for the same time. After the diathermy, he uses high frequency and applies it with a condenser electrode. Nagelschmidt uses a thick glass tube electrode filled with graphite. With this he presses into and around the region of the nerve in its various parts, breaking down adhesions if present.

A third method of electrical treatment is the application of the rhythmic sinusoidal current in full-length baths. If the application is painful the other method should be applied first and the third method applied later.

In cases where cicatricial tissue has developed, chlorine ionisation may be tried. Some writers recommend the static wave current. Surgical operation may be necessary.

Sexual Disorders.—Electricity has been much used in sexual disorders, but it has not proved of great value.

Most sexual disability is due either to nervousness or over-indulgence, and it is not easy to see how electricity locally applied could, under such circumstances, have any great value. Erb, however, has advised the use of the constant current, from 5 to 10 milliamperes. A small button-shaped electrode, positive, to the perinæum, and the other larger electrode to be moved up and down slowly over the lower dorsal and lumbar spine. Faradisation of the scrotum with a fine wire metal brush is sometimes of value in cases of impotence.

Sinuses.—Sinuses that refuse to close should be treated by the ionic method, using zinc, or salicylic ions, or the ions in a solution of iodine in potassium iodide. The method of application is described in Chapter V., page 83.

Sprains (see **Arthritis—Injuries of Joints**).

Spring Catarrh (Vernal Conjunctivitis).—This very intractable infection of the conjunctiva is sometimes sent for electrical treatment. Ionisation with quinine ions has been recommended.

Stellate Veins (see page 94).

Stiff Joints (see **Arthritis—Injuries of Joints**).

Stricture (see page 95).

Sycosis.—This may be treated by ionising the suppurating follicles with copper or zinc, needles of these metals being introduced into the affected parts. The whole of the affected skin should afterwards receive zinc ionisation from a pad covering the part.

Synovitis.—Chronic synovitis may be treated by ionisation with salicylic or iodine ions.

Tabes (see **Locomotor Ataxy**).

Tinea Tonsurans.—The fungus in the hair roots can be destroyed by ionising the scalp with copper or zinc ions. It is impossible to remove every trace of grease from the scalp and hair follicles, and unless this be done some hairs will remain infected and afterwards reinfect the scalp. When there is only one small affected patch the ionic method of treatment may be tried. After a thorough wash of the scalp with soap and water, followed by alcohol and ether, a pad soaked in 2% zinc sulphate or copper sulphate is placed in contact and allowed to stop there for half-an-hour. The pad is then connected to the positive pole, and the current started, so that the ions can migrate inwards.

Tinnitus Aurium sometimes responds to electrical treatment very satisfactorily. A bifircated electrode is used and made the anode. The electrode is like the metal part of a binaural stethoscope. To its free ends are attached the pads. The latter are placed behind the ears. The current must be turned on and off very gradually or the noises may return worse than before.

The brush discharge from the static machine and the high-frequency effluve, applied locally, have been recommended.

Trachoma.—W. J. Morton originally reported a method of treatment of trachoma by copper ions. A copper rod was slowly passed over the everted lid and a current of 2 to 3 milliamperes or more was passed for two or three minutes. Four to twelve treatments were necessary. Several cures were reported.

Ulcers.—(1) *Chronic Non-Specific Ulcers* improve at once under ionic treatment and heal rapidly. The zinc ion is generally chosen. Occasionally the zinc fails. It is then advisable to apply a solution of iodine in

potassium (1% of each) and introduce into the ulcer the negatively charged ions from this solution. The salicylic ion is sometimes effective when the zinc ion fails. The ionic method of treatment of these ulcers will often succeed when all other methods have failed. When the zinc ions are used the base and edges of the ulcer take on a pearly white hue. No further treatment should be given as long as this appearance is maintained, and so long as the edges of the ulcer are growing towards each other it is not necessary to repeat the treatment. If the iodine ions or salicylic ions are used they need not be applied again till a week has elapsed, and then only if the ulcer ceases to fill up.

(2) *Corneal Ulcer* (see page 224).

(3) *Rodent Ulcer* (see page 245).

Urinary Incontinence (see **Incontinence of Urine**).

Variocele.—The pain associated with variocele is relieved by the application of high frequency to the scrotum. Diathermy would probably be more efficacious. The patient lies on the condenser couch (Schittenhelm couch when diathermy is applied). The scrotum is enveloped in strips of lint soaked in 10% salt solution, and an electrode, made of thin lead plate, is bent so as to fit the lint surrounding the scrotum.

Varicose Veins.—These may receive high-frequency or diathermic treatment on the condenser couch or Schittenhelm couch respectively. The veins should be covered with lint strips soaked in 10% saline, and lead plates should be laid over these and connected to the diathermy or high-frequency machine.

Vernal Conjunctivitis (see **Spring Catarrh**).

Writer's Cramp.—The electrical treatment of this is unsatisfactory, even if the occupation is left off. The

passage of a constant current from the back of the neck to the forehead may be tried. Another method is to apply the same current, but to direct it from the hand to the back of the neck. The anode is placed on the palm if the cramp is of the extensors ; on the dorsum if it is of the flexors. A current of from 2 to 8 milliamperes is to be applied twice daily, for fifteen to twenty-five minutes. Complete rest from writing is absolutely essential.

Other forms of "occupation spasm" are to be treated in the same way, the anode placed opposite the affected muscles.

Warts.—Flat warts can sometimes be made to disappear by introducing magnesium ions into them. A pad soaked in 5% magnesium sulphate is placed over the region covered by the warts. One or two applications, only, are necessary. If the method is not successful ionisation with zinc should be tried. Each wart is transfixed at its base, at the level of the surrounding skin, with a zinc needle. A current of 1 milliampere should be applied for one minute. If the wart is larger than, say, an eighth of an inch in diameter, it should be transfixed twice, in two directions, at right angles. If still larger, three or four times, parallel to each other. The wart darkens in colour and drops off after about a week. A current of 1 milliampere for one minute is sufficient for each application.

CHAPTER XV

PHYSICAL PRINCIPLES

Nature of Electricity. — Very little is known of the actual nature of electricity. The question is, however, of minor importance in the application of electricity in medicine and the arts, since we are here concerned entirely with the effects to which it gives rise, not with the nature of the agent that is responsible for their production. It is necessary, however, that certain fundamental principles should be borne in mind regarding our conceptions of electricity.

In the first place it must be remembered that electricity exists everywhere, permeating all matter, but in a condition of such even distribution and perfect balance that we are unaware of its existence. When the distribution is altered the effects which are termed "electrical" are then made manifest in the effort to regain the balance. In the second place, it must be remembered there is no creation of electricity, although it is convenient to make use of such an expression. We merely alter its distribution, producing in one part an excess, in another part a deficit; hence the origin of the expressions "positive charge" or "positive electricity," and "negative charge" or "negative electricity." It must also be remembered that the subdivision of electricity into various forms, such as static electricity, current electricity, etc., does not imply the existence of so many varieties of electricity, but refers to the different ways in which it can manifest itself.

Of the views that were held concerning the nature of

electricity itself, one was that it consisted of an "imponderable fluid" pervading all matter, but that, so long as the distribution was even, neither an excess nor a deficit, there was no outward and visible evidence of it. If the balance was upset, then the effects termed electrical came into evidence. The expressions "positive electricity" or "positive charge" indicated the idea that the fluid was present in excess; "negative electricity" or "negative charge" that it was present in amount less than that in the state of even distribution. This is the "one-fluid theory" of the nature of electricity.

The modern view is that electricity is a material substance consisting of units or atoms that are $\frac{1}{1800}$th of the size of an atom of hydrogen. Each atom of matter is supposed to contain one or more of these units, or "electrons," as they have been called. A body which contains the normal number of electrons presents no electrical properties. It is only when there is an excess or deficit of electrons that these properties become manifest. When glass is rubbed with silk it is supposed, according to the old theory, to have acquired *excess* of the electric fluid, or, in other words, a *positive* charge. Now when a body *loses* some of its electrons it shows the same electrical properties as a *positively* charged body, and vice versa. It is therefore unfortunate that the term "positive" was arbitrarily chosen to express the electrical condition of a body which, according to modern research, contains a deficit of electrons.

In order to avoid confusion the terms positive and negative are used in their original meaning; the charge on glass after the latter has been rubbed with silk is regarded as a *positive* charge.

A. Static Electricity

Static electricity is most readily produced by friction. If glass is rubbed with silk both acquire an electrical

charge. Speaking more correctly, the friction brings about a redistribution of electricity, one of the rubbed bodies acquires an excess of electricity, the other losing it to a corresponding amount. It is commonly supposed that the glass acquires the excess, the silk thereby losing it to an equal degree. The glass is therefore said to be *positively* charged, the silk to be *negatively* charged. Bodies that are electrically charged acquire new properties, the most characteristic of which is their power of attracting or repelling other light bodies. It can easily be shown that they attract other objects that are light and free to move. It can also be shown that a positively charged body will attract a negatively charged body, but that two positively charged bodies, or two negatively charged bodies, will repel each other. Bodies that are similarly charged, therefore, repel each other, and those that are differently charged attract each other. These properties of electrified bodies are demonstrated by the *electroscope*. This instrument is used for the purpose of finding out whether an object is electrically charged or not, and whether the charge is negative or positive (see page 257).

Many other bodies besides glass and silk become electrically charged by friction. The same two bodies always take the same charges when rubbed together. The charge which a body takes depends upon the substance against which it is rubbed, and the charges on the two are always equal and opposite. It is possible to construct a list of substances so that when any pair of them is rubbed together the body higher in the list is positively electrified and the other is negatively electrified to an equal extent. The following is a list of this kind: catskin, glass, flannel, paper, silk, shellac.

If we rub glass with catskin the glass becomes negatively electrified, while if the same piece of glass is rubbed with silk it is positively electrified.

The electrical charges that are produced by friction remain on the bodies which are rubbed together, and do not at once flow off. The term "static" is applied to such electrical changes to signify that the electricity stays where it is produced. The term conveys the idea of electricity "at rest." Speaking more precisely, the distribution of electricity rendered uneven, in excess on one body, in deficit on the other, remains uneven ; the balance has been upset and it remains upset.

Many substances (they were formerly called non-electrics) do not become electrically charged when rubbed together. The reason is because they allow the ready passage of electricity along them and from one to another, so that the balance is restored as fast as it is upset, if indeed it can be said to be upset at all. These substances are *conductors* of electricity. Other substances do not allow the ready passage of electricity along them, so that the balance, upset by friction, is not readily restored. The latter substances, formerly grouped together as "electrics," do not conduct electricity, and are now known as "non-conductors" or "insulators."

Conductors and Insulators.—There is no sharp line of demarcation between conductors and non-conductors. All substances are conductors of electricity more or less, but some of them conduct it so exceedingly badly that they are, practically, insulators. A perfect insulator would be an absolute vacuum, but as an absolute vacuum exists only in theory—being practically unobtainable—we are at present without a perfect insulator.

The metals are good conductors. So also is carbon. Aqueous solutions of acids, alkalies and salts are less good conductors. The tissues of the body that contain salts in solution conduct electricity fairly well. Vulcanite, ebonite, shellac, sealing-wax, glass, silk are insulators.

Distilled water is an insulator. The skin, when moist, is an indifferent conductor. When dry it is a very bad conductor. The conduction of electricity by fluids and by the tissues of the body forms a subject of extreme importance for the correct understanding of the action of electricity on the body and was considered in Chapter I.

The conducting power of some substances varies with their physical state. For instance, metals when heated do not conduct as well as they do when they are cold. Carbon, on the other hand, conducts better as its temperature is raised. Absolutely pure water is a very good insulator, but the addition of a slight trace of a salt brings down the resistance enormously. A person's skin when dry has a very high resistance, but when well wetted becomes a very fair conductor; again, dry air is one of the best insulators we know of—moist air is a poor conductor. Further, the insulating power of air is increased as its pressure is increased, while, on the other hand, as the pressure is decreased its insulating properties are decreased until a degree of diminution of pressure is reached when it becomes a moderately good conductor. Further reduction of the pressure now increases the resistance, and when the pressure falls to zero electricity cannot be conducted at all, a perfect vacuum being a perfect insulator. The conduction of electricity by the so-called vacuum electrodes used in medicine illustrates the fairly good conduction of electricity along air at a certain degree of diminution of pressure.

In the application of electricity for medical purposes we have to deal mainly with the conduction of electricity through fluid conductors. The subject thus becomes extremely important, and, when it is clearly understood, a ready explanation is obtained of one of the modes of action of electricity in producing physiological and therapeutic effects on the body. The matter was considered in detail in Chapter I.

When a conductor is mounted on some insulating material and not in contact with any conductor, it is said to be "insulated," because electricity when produced on it cannot escape.

Induction.—When an electrically charged body is brought near a conductor, without touching it, the latter becomes electrically charged itself. The first body is said to *induce* electricity on the second. The first body does not part with any of its charge. It induces a redistribution of electricity on the second body, one part of the latter acquiring more than normal (a positive charge), another part therefore containing less than its normal amount (a negative charge). These two induced charges take up definite positions. Suppose that the original body was positively charged: since like charges repel each other and unlike charges attract each other, the negative *induced* charge takes up a position on the second body as near as possible to the first. The positive *induced* charge is repelled as far away as possible from the first. If the first body is now removed, the two induced charges neutralise each other—*i.e.* the distribution again becomes uniform and the second body now shows no sign of an electrical charge. Supposing that the second body is insulated: if the first body is again approached the charges are again induced. If the second body is now momentarily connected to earth, say by touching it, the positive induced charge is now repelled to earth. If the first body is now removed, the second body is now left with a negative charge upon it, because the repelled positive charge cannot return as the second body is insulated.

The phenomena of induction and of attraction and repulsion can be well shown by the electroscope.

The Electroscope.—In its simplest form this instrument consists of two gold leaves suspended from the tip of a

vertical metal rod. They lie in contact, face to face. In order to protect them they are enclosed in a glass jar, the mouth of which is closed by a cork, through which the metal rod passes, so that the leaves hang freely within the jar. The other end of the rod is outside the jar, and it bears a metal ball (Fig. 62).

When a charged body is brought near the metal ball a charge of opposite nature is induced on the latter and an equal charge, of the same nature as that on the charged body, is repelled to the gold leaves. The latter, being similarly charged, repel each other and diverge. When the charged body is removed the induced charges neutralise each other and the leaves fall together again. But if the metal ball is momentarily touched before the charged body is removed the induced charge that is repelled to the gold leaves is now repelled to earth and the leaves, being now no longer charged, fall together. If now the original charged body is removed, the charge that was induced on the ball now spreads itself over the metal rod and the leaves. The latter diverge once more. Suppose that the original body was positively charged, the leaves would then be negatively charged. If now a second charged body, the nature of the charge being unknown, be brought near the ball without touching, it will induce on to the leaves an extra charge of the same nature as that on itself. If the leaves diverge still further, the extra charge on the leaves is of the same nature as that

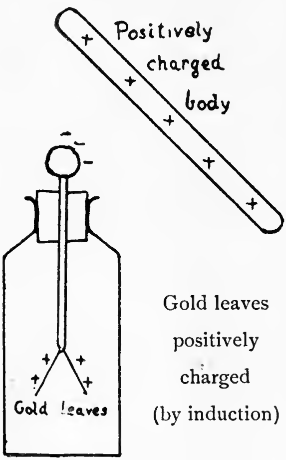


Fig. 62.—Electroscope

pre-existing on it—viz. negative. The unknown charge is therefore negative. But if the leaves approach one another the unknown charge is positive.

Density: Potential.—An electrical charge resides only on the surface of a conductor. The density of a charge is the amount of electricity per unit of surface area. If the electricity is not evenly distributed over the surface, the density must vary in different parts. The distribution is even only over the surface of a sphere, and so the density is the same all over. If the surface of a conductor is not even, the distribution of the electricity will be uneven; it will be more concentrated on the parts that are more convex, while the greatest concentration will be on edges and points. The density will therefore be greatest at edges and points, and here the electricity tends to leak off from the conductor.

The term "potential" is frequently used in reference to electrical charges. Conductors are said to be charged to a high potential or to a low potential. The potential of a charge does not refer to the actual quantity of electricity, but to the quantity in relation to the surface area of the conductor on which it resides. The following comparison may make the meaning of potential clearer. A certain quantity of air pumped into an inexpansible vessel would exert a certain pressure on the walls; if the capacity of the vessel was reduced to one half, the same quantity of air (measured in the uncompressed state) would exert double the pressure, although the quantity of air would be the same. In the case of the electrical charge, a certain quantity of electricity would charge a conductor to a certain potential. The same quantity of electricity would charge a conductor of half the capacity to double the potential. In the latter case the density of the charge—*i.e.* the *quantity* of electricity per unit of area—is doubled and the result is that the

electricity is at a higher potential or "pressure"; the electricity has a greater capacity for doing electrical work and overcoming resistance. Electricity at high potential flows or tends to flow to parts where it exists at lower potential, and if the difference of potential is high it may overcome the resistance of the air—that is, if air separates the two conductors charged to different potentials—and pass across in the form of long sparks.

The potential of the earth's surface is taken as zero. All bodies that are connected to earth by conductors (or "earthed") must be at the same zero potential.

Positively charged bodies may be regarded as bodies charged to a potential above zero; negatively charged bodies as those charged to a potential below zero.

Capacity.—The quantity of electricity that a conductor is capable of receiving is determined by the "capacity" of the conductor. As the electricity resides only on the surface, the capacity of a conductor depends upon its surface area. For electrical purposes the capacity is measured, not by the surface area, but by the quantity of electricity required to raise its potential from zero to unity. If a unit quantity of electricity is required to raise the potential from zero to unity, the conductor is said to have a unit capacity. The unit of capacity is a "farad."

When we say that a conductor has a certain capacity, it is not to be thought that it is capable of holding only a certain fixed charge. The amount of electricity that a conductor will hold depends, apart from its surface area, on the potential of the source of supply; if this is sufficiently high, electricity will pass to the conductor, raising its potential till the electricity begins to leak off. If, on the other hand, the potential of the source of supply is low, electricity will pass to the conductor till the potential of the charge on the latter equals that of the

source of supply, and no more electricity can then pass. To return to the air pressure analogy. A pump capable of delivering air at any pressure will continue to force air into a vessel, raising the pressure within it higher and higher till the air escapes through a valve ; on the other hand, if the pump delivers air at a low pressure, the pressure inside the vessel will soon equal that of the air supplied by the pump, and then no more will pass in.

The capacity of a conductor may be greatly increased by bringing close to it a second conductor without actually touching it, the two being separated by some insulating material, such as the air, or glass, ebonite, etc. Such an arrangement of conductors is termed a *condenser*, because the first conductor is now able to hold a much larger quantity of electricity than it could before the second conductor was in close apposition.

Condensers.—A condenser consists of two conducting surfaces separated by some insulating material. The latter is sometimes called the "dielectric." The capacity of a condenser depends on : (*a*) the area of the conducting surfaces—the greater the surface the greater the capacity ; (*b*) the thinness of the dielectric—the thinner the dielectric the greater the capacity ; (*c*) the material of the dielectric—glass gives a condenser a greater capacity than the same thickness of air.

The simplest form of condenser consists of two metal sheets of equal size, facing each other, with a layer of insulating material of larger area interposed, allowing them to come into close apposition without actual contact.

The most familiar form of condenser is the well-known Leyden jar (Fig. 63), which in its most common form consists of a glass bottle which is partially coated inside and out with tin-foil, and provided with a stopper of some insulating material through which passes a stout wire.

On the outer end of this is mounted a metallic knob, and from the inner end hangs a length of brass chain sufficient to make good contact with the inner coating. Here the two tin-foil surfaces are the conductors—sometimes called the "armatures"—and the glass the dielectric.

To charge a condenser one of the conducting surfaces is connected to a source of electricity, and the other surface is connected to earth. In the case of the Leyden jar, the metallic knob is connected to the source of the electricity, while the outer coat is brought into contact with earth by standing the jar on a table, or by holding the jar in the hand, grasping the outer coating. The inner coating is charged—by conduction—from the source of supply, while the outer coating is charged by *induction*, the induced charge of the *same* sign being repelled to earth, that of the *opposite* sign remaining on the outer coat, attracted by the charge on the inner coat.

Fig. 63.—Leyden Jar

Suppose that the potential of the source of supply is $+1$. The inner coat of the jar when connected to this source is thereby charged to the same potential. But a larger quantity of electricity is required to charge it to this potential than would be required if the inner coating stood by itself. Suppose the potential of the induced charge on the outer coat is $-\frac{1}{2}$. The potential of the inner coat is now $1-\frac{1}{2}$ or $+\frac{1}{2}$. The inner coat is thus brought to a lower potential than that of the supply, and, therefore, more electricity must pass to the inner coat until the potentials are equal.

To discharge the jar a bent wire is placed with one end against the outer coating, and while retaining it there, the other end is brought gradually closer to the knob. Presently a spark passes and the jar is said to be discharged.

As a matter of fact it is not completely discharged unless the wire has been brought in contact with the knob and the outer coating at the same instant, for if we try again to discharge the jar another spark will pass, though much smaller and shorter than the first. This is due to the "residual" charge, as it is called. It may be as well to mention here that when we discharge a jar the spark is not single—passing once only from wire to knob, or vice versa; what appears to be a single spark is really a series of sparks passing alternately in opposite directions at an enormously rapid rate. The oscillation may, under suitable circumstances, reach a frequency of thousands or even millions per second. The discharge of a condenser is therefore a current of high-frequency oscillation or alternation, providing certain requirements in the circuit along which the discharge takes place are fulfilled. These have been mentioned in the chapter on high frequency.

The oscillatory discharges of condensers are used for electro-medical treatment, and their application forms an important branch of modern electro-therapy—viz. high frequency and diathermy. Condenser discharges have been recently introduced for the purpose of muscle-testing and treatment of paralysis and other conditions.

The Production of Static Electricity for Medical Purposes.—Static electric machines are used to generate a continuous supply of static electricity, and are of two kinds, frictional and inductive. The old-fashioned revolving glass cylinder, with an amalgamated leather rubber and brass collector or prime conductor, is an example of the frictional type. This type of machine is never used for medical purposes, and is now seen only in physical laboratories.

Induction or influence static machines are much more reliable, but how they work is not easy to describe or understand.

The principle may be outlined as follows :—

A body, *A*, is charged positively and brought near another body, *B*. *B* is therefore charged by induction, as described under "Induction." *B* is momentarily connected to earth, whereupon the positive induced charge escapes, and the negative induced charge remains. *B* and *A* are now separated from one another. The induced negative charge on *B* is collected and stored on another fixed conductor, while the original positive charge on *A* can be used over and over again to induce fresh charges. The mechanical energy expended in separating the oppositely charged bodies, *A* and *B*, is converted into electrical energy.

Two types of influence machine have been described in Chapter XIII.

(*B*) Current Electricity

If two conductors at different potentials are connected by a wire, the difference of potential will be equalised and a current of electricity, of momentary duration, will pass along the wire. If the conductor at the higher potential can be continuously supplied with electricity, a continuous current will flow along the wire. Continuous currents of electricity can be obtained by *chemical, thermal* or *mechanical* methods. The currents that are supplied by the different types of cell are obtained by chemical methods. Batteries of these cells form an important source of electrical supply for medical purposes, and the principles on which they work will be considered first.

Production of Electrical Currents by Chemical Methods.—If two dissimilar metals are brought into contact a slight difference of potential is set up between them, that of one being raised (positive), that of the other being lowered (negative). The degree of difference is always

very slight, and it varies according to the metals taken, and it does not depend upon the amount of metal or the extent of surface in contact.

Here again it is possible to draw up a list of substances —metals or conductors in this case—each of which will be positively electrified when brought into contact with any metal succeeding it, and negatively electrified with any metal coming before it in the list :

+ Sodium	Copper
Zinc	Silver
Lead	Platinum
Tin	– Carbon

Carbon is not a metal, but is included in this list on account of its good conducting properties, and from the fact that it is now used so much in all branches of electrical work. If zinc and copper be brought together, zinc is positive and copper is negative, while if copper and carbon be brought together, the copper is positive and the carbon negative. The more one metal is removed from another in the list, the greater is the difference of potential. It will be noticed that those metals nearest the + end of the list are the most oxidisable, while the reverse holds good for metals at the – end.

It is impossible, however, to obtain an electrical current by simply bringing dissimilar metals into contact. If the circuit is completed by connecting together the free ends of the two metals in contact, either directly or by means of a third metal, new contacts of dissimilar metals are made and the difference of potential first set up would be effaced. Apart from this, the production of a continuous current of electricity, by simply bringing dissimilar metals into contact, would be impossible, according to the principle of the conservation of energy, seeing that the metals are not altered or used up. If,

however, the two metals in contact are immersed in some fluid that is capable of acting chemically on one of them or acting more vigorously on one than on the other, a continuous current can be produced while the chemical action proceeds. Thus if a piece of copper and a piece of zinc are fixed together, end to end, the copper becomes negatively charged, the zinc positively charged. If the joined metals are immersed in dilute sulphuric acid, a circuit is now completed and an electrical current flows from the zinc, through the acid, to the copper, and through the copper into the zinc. Simultaneously, the zinc is slowly dissolved by the acid. If the joined metals are bent so that only the free ends are immersed in the acid, the junction being outside, an electrical current will flow as before and in the same direction. Such an arrangement is known as a "simple voltaic cell." It serves to illustrate the chemical changes that occur during the production of an electrical current and to explain the meaning of some commonly used terms.

Voltaic Cell.—A simple voltaic cell may be constructed by filling a beaker with 10% sulphuric acid, partially immersing it in two strips of metal, one of zinc, the other of copper. These strips are placed parallel to each other and with one end of each above the surface of the acid. If the strips do not touch one another, above or below the surface of the acid, the following changes occur. The zinc gradually dissolves in the acid, and zinc sulphate and hydrogen are formed. The former dissolves, while the latter escapes in the form of bubbles. These are seen to form and to escape at the surface of the zinc. If, however, the zinc is pure it is not dissolved by the acid and it undergoes no chemical change till it makes contact with the copper. If the contact is made *outside* the acid, either directly or by means of a wire, the zinc begins

to dissolve and the same chemical change takes place. The hydrogen bubbles, however, make their appearance on the *copper*, not on the zinc. Some escape from the copper to the surface of the acid, but most of them adhere to the metal and soon cover it completely. While the zinc is dissolving a current of electricity continuously passes around the circuit composed of the metal strips, their connecting wire and the dilute acid.

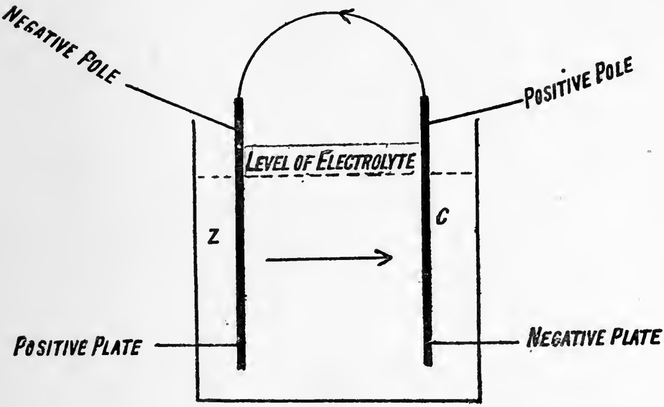


FIG. 64.—Plates and Poles of a Voltaic Cell

The current starts in the cell where the zinc is in contact with the acid. It passes through the acid to the copper plate. It then passes up the copper plate, and then across to the zinc plate, outside the acid, along the connecting wire. By passing down the zinc to the acid again, the passage along the circuit is completed. The direction of the current of electricity is indicated by the arrows in Fig. 64.

If impure zinc is used chemical changes similar to those described would have occurred, and the current would have passed in the same direction. In addition, however, small "parasitic" currents would also have

been produced. Commercial zinc contains small quantities of other metals. There are, therefore, dissimilar metals in contact, and when they are immersed in sulphuric acid currents are formed in the way mentioned in the preceding paragraph.

Certain names are given to the various parts of a voltaic cell, and as they are continually used it is necessary to be quite clear regarding their meaning.

In any cell there is an external circuit and an internal circuit, a positive plate and pole, and a negative plate and pole. It is important to distinguish between *plate* and *pole*.

In Fig. 64 that part of the circuit within the fluid of the cell is called the *internal circuit*, while that outside is the *external circuit*. In any circuit or part of a circuit, that part from which the current is coming is positive to a part to which current is flowing.

Bearing this in mind, it will be seen that that portion of the zinc which is below the level of the fluid is positive to that part of the copper which is also below the level of the fluid. In the external circuit we see that the part of the copper outside the liquid is positive to the corresponding part of the zinc. These *dry* portions of the plates are called the poles. If we attach a wire to each of these, the free extremities of these wires become the poles.

Thus it will be seen that the wet portion of the zinc is the *positive plate* and the dry portion is the *negative pole*, while the wet portion of the copper is the negative plate, the dry portion is the positive pole. This may seem very confusing, but it is not really so, and if the student will take the trouble to get the idea thoroughly there is little chance of his being confused by any of the various arrangements of circuits he will meet with in future.

It is customary when referring to the plates of a battery to speak of the *poles* and not of the *plates*. The

zinc is thus the negative pole and the other element, be it carbon, copper, or platinum, is the positive pole.

The electrical current that flows around the circuits of a voltaic cell soon diminishes in strength. It becomes feebler and feebler and finally ceases altogether.

The explanation of this is that by the accumulation of minute bubbles on the copper plate the latter is practically transformed into a hydrogen plate, which is electropositive to zinc, and tends to set up a current in the reverse direction. Also, the film of gas forms a layer of high resistance to the flow of the original current.

A cell in this condition is said to be "polarised." The prevention of polarisation is one of the most important objects in the design of a useful cell. The great variety of cells that have been devised have their origin in the various methods that have been adopted to overcome this tendency, and thus give as nearly as possible a constant current during their period of activity.

A simple cell like that described is useful for the purpose of demonstration, but is of no value for medical purposes, because the current so quickly diminishes on account of polarisation, and soon falls to zero. Polarisation can be prevented in various ways. One way is to add an oxidising agent, such as potassium bichromate, to the acid solution. The hydrogen is oxidised as soon as it is formed. This method is used in the *Poggendorff* cell. In this cell, known also as the "bichromate" cell, carbon is used instead of copper. In the *Leclanche* cell zinc and carbon are used. The zinc is immersed in a solution of salammoniac (ammonium chloride) contained in a glass jar. The carbon plate is placed inside a porous pot and packed tight round it are fragments of manganese dioxide and powdered carbon. The porous pot thus filled is placed in the jar containing the salammoniac solution. When the zinc and the carbon are connected by a wire, a current passes from the carbon to the zinc

outside the cell, and from the zinc to the carbon inside the cell. Fluid is unable to pass through the wall of the porous pot, but the electric current readily traverses it. The zinc dissolves in the salammoniac solution, forming a double chloride of zinc and ammonium, and ammonia gas and hydrogen are liberated. The ammonia dissolves and the hydrogen is oxidised by the manganese dioxide, so that polarisation is prevented. The oxidation is slow, so that if the cell is made to give a current continuously for several minutes polarisation begins and the current begins to diminish in strength. If the cell is allowed to rest, the free hydrogen will be oxidised, and the cell will then provide a current of undiminished strength.

Dry Cells.—These have almost entirely supplanted other cells for medical purposes. They are small and clean, and a number can be packed away in a case of small dimensions, so that a portable battery is at hand. They are really modified Leclanche cells, in which the solution of salammoniac is replaced by a moist, pasty composition. They tend to run down very slowly even if they are not used, but they will last from six months to two years if their use is not excessive and the best types are used. The battery of dry cells in the portable cases can be replaced when exhausted, and some makers allow 50% of the original price for the old cells in exchange for new ones.

These dry cells can be obtained from most electrical dealers.

Leclanche cells have an E.M.F. of about 1·5 volts when new, and their internal resistance is from ·75 to 1·5 ohms —the smaller the cell the higher the internal resistance. They are now almost universally used in portable batteries.

Accumulators.—Accumulators, or storage batteries, as they are often called, are the most satisfactory means we possess of obtaining electricity from chemical

action. The name "storage battery" is not correct. We do not store electricity in an accumulator, but if we take one that is run down and drive a current through it in the opposite direction to the current it gave out when working, we can restore the plates to their original condition and so give it a new lease of life, so to speak—and so long as we do not charge or discharge the cell at a greater rate than that for which it is designed, this process can be repeated almost indefinitely.

An accumulator consists of a vessel containing sulphuric acid diluted till its specific gravity is 1200. In the acid are immersed lead plates made in the form of grids. Two of these plates are negative, one positive. The spaces of the grids are filled with a paste composed of litharge in the case of the negative plates, and red lead in the case of the positive. The plates lie close together, face to face, without touching. The internal resistance of an accumulator cell is extremely low. Each cell gives 2 volts under ordinary working conditions and continues to do so until about 75% of its charge is spent. If the cell be discharged still further the voltage begins to fall. It should never be allowed to fall below 1·8, nor should it ever be left at this latter figure for any length of time; it should be recharged at once. If this be neglected, a white deposit appears on the plates—insoluble sulphate of lead. This increases the internal resistance and diminishes the capacity of the cell, and it may be safely stated that a cell which has once become markedly sulphated can never be restored to its original condition. All cells have a certain rate of charge and discharge, which depends on the size and capacity, and which should never be exceeded. The charging current is usually about 10% of the full capacity. That is, a sixty-ampere-hour cell should not be charged with a greater current than 6 amperes. This, continued for ten hours, would fully charge the cell.

The charging of an accumulator should be continued until the voltage rises to 2·5 volts per cell. The voltage remains at this for a short time only after charging is stopped, when it declines gradually to 2 volts.

Accumulators are also known as "secondary batteries" in contradistinction from the "primary batteries" as those previously described are often called. Primary batteries cannot be recharged like secondary batteries when exhausted.

Bichromate Batteries.—For cautery and working large spark coils the bichromate battery is the most easily managed where some form of *primary* cell must be used. The plates are of zinc and carbon. They should be of large size, placed close together to reduce the internal resistance to its lowest limit, and arranged so that they may be readily removed from the exciting fluid the moment the current is no longer required. The zincs must be kept well amalgamated. The exciting fluid is prepared as follows:—1 pound of potassium bichromate is dissolved in 8 pounds of hot water. Then add slowly 2½ pounds of strong sulphuric acid, stirring constantly all the time. While still hot, dissolve in the mixture 3 ounces of bisulphate of mercury. Each cell, when freshly charged, has an E.M.F. of 2 volts, but this tends to decline as the cell is used—due to the gradual weakening of the exciting fluid. When this becomes green in colour it should be thrown out and fresh solution put in. These cells should be thoroughly washed and cleaned every three or six months, according to size, and care taken to remove all the crystals of chrome alum which will be found sticking to the plates and acid vessel. The zinc plates are gradually dissolved as part of the action of the cell and will eventually have to be replaced. This is not difficult in most forms now obtainable.

The current produced in the ways described—*i.e.* by chemical means—is known sometimes as the "galvanic" current, sometimes as the "constant" current, by reason of its unvarying direction and uniformity of strength. The "direct" current is also a constant current, but the name "direct" is usually applied to it when it is obtained from the main.

Electrical currents can also be obtained by mechanical methods. These will be described shortly.

The Measurement of Electrical Currents.—This is a subject of great importance in the application of electricity for treatment and diagnosis. During the flow of the current electricity is constantly passing along the circuit, and the terms "strong" or "weak," as applied to the current, are used in reference to the *quantity* of electricity that is passing. The strength of an electrical current depends upon two factors: (1) the electro-motive force and (2) the resistance of the circuit. These terms will be explained.

Electro-motive Force.—Whatever produces or tends to produce a transfer of electricity is called electromotive force. Thus, when two electrified conductors are connected by a wire, and when electricity is transferred along the wire from one to the other, the tendency to this transfer which existed before the introduction of the wire and which, when the wire is introduced, produces this transfer, is called the electro-motive force from the one body to the other along the path marked out by the wire.

The water analogy will perhaps help to make this clearer. If two vessels containing water be joined by a pipe and we increase the pressure in one of them, the water will flow from the one in which the pressure is greater until the pressure in both becomes equal. Again, if the water is at a higher level in one vessel than in the

the other, it will flow from the former to the latter until the level is the same in both. In the same way when any two electrified bodies are joined together by a wire, electricity will flow from the body on which the charge exists at high potential to the body on which the charge exists at lower potential. The inherent force which starts and maintains the current is what is known as electro-motive force—briefly written E.M.F. The potential of the earth is always taken as the zero of electric potential.

The unit of E.M.F. is the "volt." A single Daniell cell produces an E.M.F. that is very slightly greater than one volt.

Resistance.—It has already been mentioned that different substances vary enormously in their power of conducting electricity, some conducting it readily, others so badly that they are practically non-conductors or insulators. However well a substance conducts electricity there is always some resistance to the flow.

The resistance of a conductor depends on certain conditions.

It varies

(*a*) Directly as the length.

(*b*) Inversely as the area of the cross section.

(*c*) With the nature of the material of which the conductor is made.

(*d*) To a certain extent with the temperature.

(*a*) and (*b*) are sufficiently obvious. With regard to (*c*), a conductor made of silver is found to have a lower resistance when compared with one made of any other material of similar shape and size. The resistance of copper is very slightly greater than that of silver. Platinum has a resistance about six times greater than that of silver and iron about nine times greater.

As a rule alloys have a resistance much greater than

pure metals. An alloy known as German silver has a resistance about fourteen times greater than that of silver, while another called rheostene has about forty-four times the resistance of copper. Speaking generally, the resistance of metals increases with an increase in temperature. Carbon and aqueous solutions of salts, acids and bases decrease in resistance as the temperature rises.

In speaking of resistance it is useful to have a unit so as to be able to compare the resistance of various circuits or the different parts of a single circuit. The unit of resistance is called the "ohm," after the scientist who formulated the law which is known by his name. An ohm is represented by the resistance of a column of pure mercury at 0°C. of a uniform cross section of one square millimetre and 106 centimetres long.

The Unit of Current.—The unit of current is the "ampere." It is the current produced when an electro-motive force of 1 volt acts through a resistance of 1 ohm. The strength of a current depends upon the electro-motive force and resistance. If the electro-motive force is increased, the current will be increased ; if the resistance is increased, the current will be diminished. In other words, increase of the force that produces the transfer of the electric fluid (or electrons) will cause a larger quantity of electric fluid (or electrons) to pass along the circuit, while increase of the resistance to the passage of the fluid (or electrons) will lessen the quantity of fluid (or electrons).

The relation between strength of current, electro-motive force and resistance is stated in Ohm's law.

Ohm's Law.—Ohm's law is as follows :—The current varies directly as the electro-motive force and inversely as the resistance.

Expressed in symbols it is:

$$C = \frac{E}{R} \qquad \text{where}$$

C = The current.
E = Electro-motive force.
R = Resistance.

From the above equation we obtain

$$E = CR$$

and

$$R = \frac{E}{C}$$

so that with any two of the factors given, the value of the third is obtainable by a simple calculation. This is probably the most important law that has been laid down relating to electricity, and is one that the student should be thoroughly familiar with it in all its aspects. It underlies every intelligent application of the electrical current in medicine.

Other Practical Units.—(1) *Unit of Quantity.*—This is the "coulomb" and represents the quantity of electricity corresponding to a current of 1 ampere flowing for one second.

(2) *Unit of Work.*—The unit of the work done is known as a *watt.* It is the product of the volts and the amperes. A current of 1 ampere at a pressure (E.M.F.) of 1 volt flowing for one hour is called *one watt hour.* The Board of Trade unit, as used by all supply companies, is 1000 watt hours. A current of 10 amperes at 100 volts flowing for one hour represents 1000 watt hours, for which the usual charge is sixpence. This is not a unit used in medical electricity, but, as many will obtain their supply from the street mains, it is as well to know what a Board of Trade unit really means.

(3) *Unit of Capacity.*—It was previously mentioned

that the capacity of a conductor was measured, not by its surface area, but by the quantity of electricity required to raise its potential from zero to unity. If a coulomb is required to raise the potential of a conductor 1 volt, that conductor is said to have a capacity of 1 *farad*. The size of such a conductor would be so enormous that the *microfarad*—that is, one-millionth of a farad—is taken as the unit of capacity.

Internal Resistance.—This refers to the resistance to the flow of current inside a generator or originator of an electro-motive force. In the case of a dynamo-electric machine it is the resistance of the copper conducting wires with which the machine is wound—and in the case of the battery it is the resistance of the solution between the plates. In the former case it depends on the length and size of the wires; in the latter, on the nature of the solution, the area of the plates, and their distance from each other. For a generator to produce a large current it is essential that its internal resistance be kept very low. A resistance inside a cell has to be overcome just the same as if it were in the external circuit, and where the external resistance is very low, a high internal resistance would have a very serious effect on the output of current. On the other hand, with a very high resistance in the external circuit the internal resistance does not signify very much on account of the small proportion it bears to the total resistance of the circuit. To take an example: if the internal resistance of a cell be 3 ohms, and the resistance of the external circuit be 1 ohm, three-fourths of the E.M.F. of the cell will be used up in overcoming its own resistance, leaving only one-fourth of the original E.M.F. available for the outer or useful circuit. If, again, the internal resistance be the same, and the external resistance be 97 ohms, then only $\frac{3}{100}$ of the E.M.F. will be used up inside the cell, leaving $\frac{97}{100}$ available for the

outer circuit. In the first example 75% of the total E.M.F. was wasted in the cell, in the second only 3%.

Arrangements of Cells.—If we have a number of cells of any kind we can join them up in various ways to suit our requirements. Suppose we have twelve cells, each of which is capable of supplying a current of 1 ampere at an E.M.F. of 1 volt. It will be more convenient for the sake of clearness to assume that the cells have no internal resistance. We will also suppose that we have a 12-volt incandescent lamp with which we wish to examine some part or cavity of the body. This lamp requires an E.M.F. of 12 volts to bring it to full incandescence. To obtain this we join the positive pole of the first cell to the negative of the second, and the positive of the second to the negative of the third, and so on to the end of the row, so that we have a free positive pole at the first cell, and a free negative pole at the twelfth, thus :—

FIG. 65.—Diagram of Twelve Cells joined in Series

If we now connect a volt-meter to the two wires from the ends, the instrument will register 12 volts, and if we replace the volt-meter by the lamp it will light up to its full candle-power.

The cells as arranged above are said to be connected in *series*, and the effect of the arrangement is to increase the voltage directly as the number of cells—the total E.M.F. being equivalent to the E.M.F. of one cell multiplied by the number of cells. It does not increase the number of amperes beyond what is available from a single cell—that is, 1 ampere, which is probably more than the lamp requires. Now suppose we have a cautery which has a resistance of $\frac{1}{12}$ ohm and requires a current of 12 amperes to bring it to the proper heat. It is quite

clear that the series arrangement will not do, as the amount of current available is quite insufficient to affect the cautery. Also it will be seen that an E.M.F. of 1 volt is all that is necessary to send a current of 12 amperes through a resistance of $\frac{1}{12}$ ohm. Thus we have no object in increasing the voltage beyond that given by one cell, but the amperage of the current must be increased till it reaches 12. We now join all the positive poles together and do the same with the negatives, thus :—

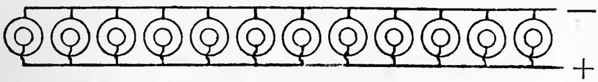


FIG. 66.—Diagram of Twelve Cells joined in Parallel

The result here is the same as if we had one big cell twelve times the capacity of a single cell. The voltage of any given cell is the same whatever the size, but the larger the cell the greater the quantity of current it is capable of supplying. We will now find that the difference of potential between the terminals of the arrangement is just 1 volt, but a current of 12 amperes can be obtained, so that if we connect up the cautery it will glow a bright red and be ready for use. The cells connected as above are said to be arranged in *parallel.*

Various combinations of the series and parallel arrangements are also possible. If we wanted a current of 2 amperes at a pressure of 6 volts, we would arrange the first six cells in series, and also the second six cells in the same way, and then join these two sets in parallel. This is a series-parallel arrangement—other modifications of which will suggest themselves.

Current Density.—When a current flows along a narrow conductor its *density* or " concentration " will be greater than that of the same current when it flows along a broad conductor. The density of a current in one

conductor is the strength of the current divided by the cross-sectional area. It is of great importance, when applying currents to the body, to avoid too great a density. The amount of current that the body can tolerate depends upon the degree of stimulation of the sensory nerve-endings in the skin and the force of contraction of the underlying muscles. The greater the density, the stronger the stimulation and the more violent the contraction. So if the current enters and leaves the body through small electrodes, only weak currents can be passed. If we wish to employ large currents we must use large electrodes, and see that they are well adapted to the part. For example, if we wished to apply a current of 50 milliamperes to a limb, and used electrodes, say, one square inch in area, the patient would experience a very sharp pain at the points of contact, and if the application be persisted in for some minutes, a blister or even an ulcer will eventually form. The reason is that the whole 50 milliamperes passes through an area of one square inch. If we use larger electrodes, say five inches by five inches, the current density, instead of 50 milliamperes per square inch, would be only 2 milliamperes per square inch. In this way we can employ the same amount of current without discomfort or harm to the patient.

Electric Current and Magnetism.—There is one other peculiar manifestation of electricity when passing through a conductor that has not yet been mentioned. If we take a wire through which a strong current is passing, dip it into some iron filings and then remove it therefrom (the current still flowing), some of the filings will be found attached to the wire, and will not all fall off when the wire is shaken, but if we stop the current flowing they all fall away at once, and so long as the current is not flowing the wire will not pick up any more. The reason for this is, that when an electric current flows

through a wire there is always a field of magnetic force surrounding it. The lines of magnetic force are at right angles to the direction of flow of current. This magnetic field is a necessary accompaniment of an electric current, and is inseparable from it. It is the presence of this magnetic field which causes the magnetic needle to be deflected in the way to be described later.

The Magnetic Needle.—If a straight piece of hard steel wire, such as a knitting needle, be magnetised, and suspended so as to be free to move in any direction, it will gradually come to rest, with one end pointing to the north and the other to the south. These ends are called the North Pole and South Pole respectively, and one is a necessary accompaniment of the other. That is to say, if we take any piece of magnetic substance, one end of which shows the presence of magnetism of the north variety—then the other end will be also magnetic, but of the south variety. If we take a bar magnet and cut it through at the middle where the magnetic attraction seems weakest or even lost, the result is two complete magnets, each having a north and a south pole.

The knitting needle arranged as above is merely another form of compass, and both are really bar magnets.

Properties of Magnets: Attraction and Repulsion.—Magnets possess properties analagous to those of electrified bodies. Like magnetic poles repel one another; unlike poles attract each other. A magnet is also able to *induce* magnetism in a piece of iron or steel that is brought near to it without actually touching it. Any one pole of a magnet will induce magnetism of an *opposite* kind in that part of the iron that is nearest to it, and of the *same* kind in that part that is farthest away. It is for this reason that magnets attract particles of steel or iron. Magnetism is induced in them—that of the same

kind being farther off than that of the opposite kind, so that the particles are attracted with a greater force than that with which they tend to be repelled. It will be remembered that electrified bodies also attract other light bodies, because changes are induced on them.

Lines of Magnetic Force.—Particles of iron or steel and magnetic needles, when brought into the neighbourhood of a magnet, at once arrange themselves in definite lines.

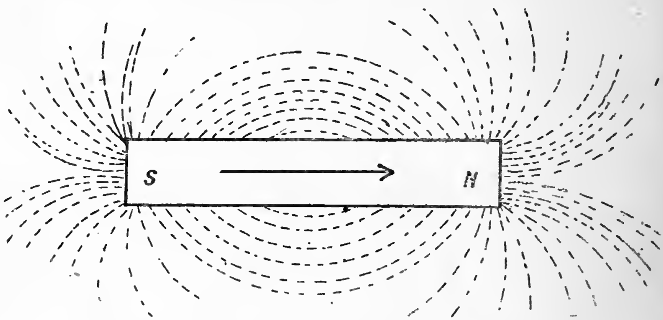


FIG. 67.—Lines of Force around a Bar Magnet

Magnetism is induced in them, and they take up positions determined by the resultant of the attracting and repelling forces. The lines along which the magnetic induction acts are known as the "lines of magnetic force." As the pole of a magnet is approached, the force of induction increases and we speak of an increased number of lines of force in the region of the poles. A magnet is surrounded by lines of force. Fig. 67 shows a bar magnet with the surrounding lines of force. If two magnets are brought into the neighbourhood of one another they tend to arrange themselves so that their lines of force assume the same direction where they overlap. If a magnetic needle is suspended it sets itself north and south, so that its own lines of force

—the majority of which lie between its two poles—may coincide with those of the earth.

It has been mentioned that a wire along which a current is flowing is surrounded by a magnetic field. The lines of force have a definite direction. They are arranged concentrically around the wire conveying the current in a plane at right angles to it. If a magnetic needle is placed close to a wire along which a current is flowing, the north-south direction previously taken under the influence of the earth's magnetic lines is now altered by the new magnetic lines created by the current. The magnetic needle now alters its direction so that its own lines of force can coincide as far as possible with those created by the current. The position which the north-seeking pole of the needle will assume can be foretold if the following illustration is remembered :—

Imagine a man swimming in the wire in the same direction as the current and turned so as to face the needle, then the north-seeking pole of the latter will be deflected towards his *left* hand.

The Galvanometer.—This is an instrument designed for the measurement of electrical currents. An *ampere-meter* (or ammeter) is a galvanometer graduated so as to indicate on its scale the number of amperes passing through it. A milliampere-meter indicates the current in thousandths of an ampere, 1 milliampere being $\frac{1}{1000}$th of an ampere.

A *volt-meter* is a galvanometer that measures electromotive force.

These instruments work on the principles described above ; the current causes the deflection of a movable magnetic needle, and the amount of deflection is the measure of the strength of the current.

Until comparatively recently all galvanometers were of the magnetic needle type. While undoubtedly

accurate, they laboured under certain disadvantages. They had to be carefully levelled, and placed in proper relation to the magnetic meridian to bring the pointer to zero. The latter always took some time to come to rest, and the readings were easily disturbed by the presence of magnetic bodies near by. It is not necessary to refer to them further, as they are being displaced by instruments of the "moving coil" type, one of which is shown in Fig. 68.

Whereas in the original form of instrument the magnetic needle was movable and the wire conveying the current stationary, in the moving-coil form the reverse arrangement is seen. The magnet—which is U-shaped—is stationary, and between its poles is the coil of wire that conveys the current. This coil is movable and to it is attached an indicator that moves over a scale calibrated to indicate the number of milliamperes.

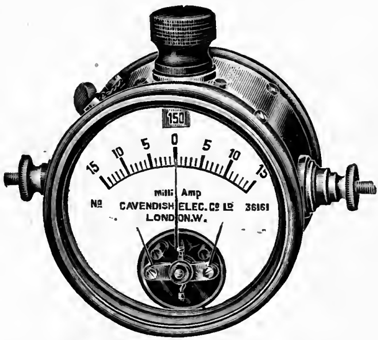


Fig. 68.—Milliampere-meter of the "Moving Coil" Type

These instruments read accurately in any position, are quite independent of the earth's magnetism or the presence of magnetic bodies, and they are "dead beat"—that is to say, the pointer quickly indicates the amount of current passing, without first swinging to and fro for some time. The instrument shown reads to 15 milliamperes. As this is too small for some purposes, it is provided with one or more shunts, which can be switched on or off as desired. The principle of the shunt is that when a current has two paths in which to flow,

it divides itself between the two, so that the current strength in each path is inversely proportional to its resistance. The arrangement is shown diagrammatically in Fig. 69.

As there shown, all the current that passes through the instrument will flow through the coil which causes the needle to move. The resistance of the shunt marked 10 is so adjusted that when it is brought into circuit $\frac{9}{10}$ of the total current passes through it, and $\frac{1}{10}$ through the coil controlling the needle. Therefore the total current passing will be ten times that indicated by the instrument. If the other shunt is used the readings are to be multiplied by 100. The knob on the top of Fig. 68 is for switching the shunts in or out of circuit. As it is revolved, the figures 1, 10, 100 pass in succession behind a small opening in the top of the dial, indicating which shunt is in circuit. In some instruments, however, the figures indicate the maximum current recorded when that particular shunt is in circuit. In the instrument shown in Fig. 68, the number 150 is shown, and it means that the instrument now records between zero and 150 milliamperes. When the zero is showing it means the whole instrument is out of action. In this position it is impossible for the instrument to be injured by the accidental passage of a heavy current through it, which would probably cause serious, if not irreparable, damage. Shunted instruments are very little more expensive than plain

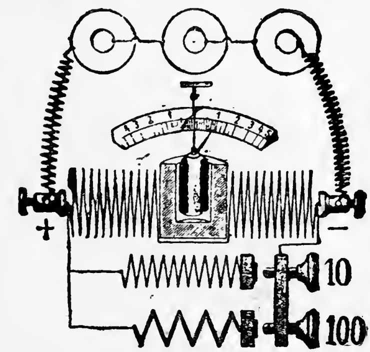


FIG. 69.—Arrangement of Shunts in Milliampere-meter

ones, and should always be selected when buying an outfit.

The Electro-magnet.—It was shown that a wire carrying an electric current became magnetic and would attract iron filings. If we take a piece of soft iron rod and wrap this wire around it, it will impart its magnetism to the iron, which will become strongly magnetic, especially if the wire is wrapped many times round and a strong current sent through it. This arrangement constitutes an "electro-magnet." An electro-magnet is only magnetic when an electric current is traversing its wire helix, provided the core—as it is called—is composed of *soft* iron or *soft* steel. Magnets on this principle can be made capable of lifting many tons' weight. They lose their magnetism entirely when the current is cut off. If the core should be made of very hard steel, a portion of the magnetism remains after the current is cut off. This core may be removed from the centre of the wire winding, and will retain more or less of its magnetism indefinitely. In this way permanent magnets are made.

Electro-magnetic Induction.—The first observations of this most interesting and important subject were made by Faraday. He found that in a closed circuit an electric current of momentary duration is induced when a magnet is approached to this conductor or withdrawn from it. He also found that if a current were made to pass through another circuit near, but quite detached from, the first one, a momentary current passed through the latter, both when the current started and when it was interrupted. The current is produced by virtue of the magnetic field set up and removed in the neighbourhood of the original closed circuit. These induced currents, as they are called, only appear so long as the magnetic field is varying in strength. The current induced at the starting of the inducing current is in an *opposite* direction to the latter, while that

produced when the inducing current is interrupted is in the *same* direction as the inducing current. It will thus be seen that whether we use a permanent magnet, an electro-magnet or a length or coil of wire carrying a current for our purpose, so long as we subject a closed circuit to a varying field of magnetic force, currents of electricity are set up in the closed circuit. These currents will vary in direction of flow according as the magnetic field is increasing or decreasing in strength.

Simple as the fundamental principle of the induction of currents is, it is perhaps the most important of all as regards the practical applications of electricity. The dynamo, motor, induction coil, telephone, etc., are all based on the principle of electro-magnetic induction.

Self-Induction.—Take a length of insulated copper wire, say two or three yards, straighten it out and attach one end to one terminal of a cell possessing high internal resistance, such as a Leclanche cell. Bring round the other end (both ends must be stripped of their insulating covering for an inch or so) and touch the other terminal of the cell with it for a moment. A very tiny spark will be seen at the instant the wire leaves the terminal. It may be necessary to do this experiment in a darkened room, so small is the spark.

Now coil up this length of wire into a close spiral by winding it on a ruler, and repeat the experiment. At the moment when the circuit is broken and the current ceases to flow, a spark that is distinctly brighter will be seen at the point where the circuit is interrupted. This is the result of the induction of new currents in the turns of the spiral at the moment the original current ceases to flow. These new currents flow in the *same* direction as the latter, and so reinforce it. A brighter spark is therefore produced. At the moment when the circuit is *completed,* new currents are again induced, but these flow

in a direction *opposite* to that of the original current, and so weaken it. The weakening is only momentary, because the induced currents flow only for a moment, and therefore all that they do is to retard the rise of the original current to its full strength while they are flowing.

The development of induced currents in the same circuit as that in which the inducing current is flowing is spoken of as "Self-Induction." If we introduce a rod of iron into the spiral, and the experiments are repeated, the effects described above will be further increased. Stronger currents will be induced at make and at break of the circuit and will further weaken the inducing currents at make and further reinforce it at break.

We can vary the amount of this self-induced current by increasing or decreasing the number of turns in the spiral, by varying the strength of the original current, and by inserting or withdrawing an iron core.

The Alternating Current.—The current of which we have been speaking up to the present is the constant current, the current that is flowing continuously always in the same direction and with strength unvaried. An alternating current is one that is constantly reversing its direction of flow. The reversals may be rhythmic or arrhythmic, regular or irregular, gradual or abrupt, frequent or infrequent. Fig. 9 (p. 23) is a graphic representation of an alternating current of which the reversals are rhythmic, regular, gradual and frequent. When an alternating current is spoken of without further qualification it is usually understood to be of the type represented in the figure. From *A* to *B* the current rises from zero to its maximum ; from *B* to *C* it falls again to zero. From *C* to *D* the current again rises from zero to maximum ; from *D* to *E* it falls again to zero. From *C* to *E* the current is flowing in the opposite direction. The complete course, from *A* to *E*, is spoken of as one

complete cycle or phase. The height of the curve above the base line at any one spot is proportional to the voltage and the length along it to the time intervals. The alternating current is produced by a dynamo, and it will be seen in the next paragraph how it is generated. These currents are frequently named "sinusoidal," because their graphic representation is approximately a sine curve. In many districts the town

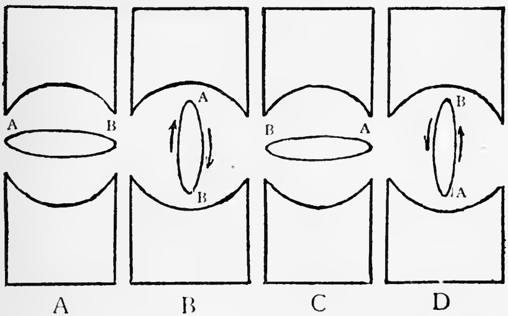


FIG. 70—To illustrate way in which an Alternating Sinusoidal Current is produced

supply is an alternating current (AC). In others it is a constant or "direct" crruent (DC).

The Production of Alternating Currents.—When a coil of wire is made to revolve in a magnetic field an electrical current will flow round the coil. On this principle currents are generated by the dynamo.

In Fig. 70 (*A*), a magnet is shown, and between its poles is a single coil of wire. This coil rotates in the magnetic field between the poles of the magnet. During its rotation, when it is in the position shown in the figure (*A*), equidistant from both poles, no current flows around it. During its rotation through a right angle (one quarter of a complete revolution) a current flows around it, starting from zero, its strength gradually increasing and

attaining its maximum value when the coil has the position shown in Fig. 70 (*B*). During the next quarter of a revolution the current gradually falls again to zero. During the third quarter the current again increases to a maximum, and during the fourth quarter it gradually reaches zero again. The current that flows during the last two quarters of the revolution is in the reverse direction. For the first half of the revolution the current is in one direction; for the second half it is in the opposite direction. During each half it starts from zero, reaches a maximum and again falls to zero. This current is the alternating current described in the previous paragraph, and may be graphically represented, as in Fig. 9. The curve shown, *ABCDE*, corresponds to one complete revolution of the coil. The number of these complete cycles per second depends upon the rate of revolution of the coil. The "frequency" or "periodicity" of an alternating current refers to the number of these complete revolutions per second. Thus if the periodicity of the current is 100, the coil is revolving 100 times per second; the length of the curve recording one complete cycle would be $\frac{1}{100}$th of a second, and there would be 200 reversals of direction (or alternations) each second.

While it is possible to evolve a sinusoidal current from an ordinary battery, we may say that all alternating currents have their origin in dynamo machines. The number of cycles per second—*i.e.* the frequency—of these currents used to be 100 to 130, but of late, lower frequencies have become more common—from 40 to 60.

The Dynamo.—It may be said that over 99% of the electricity used for various purposes is obtained from dynamos. By far the most convenient source of electricity for medical purposes is the dynamo at the power station, from which the supply is taken along the mains

to the places where it is desired. In places where there is no main supply, the current may be derived from a small dynamo worked by a gas or oil engine or by water-power.

The device which has been described above for the production of an alternating current is really a dynamo in a very simple form. A dynamo consists of three essential parts: (1) the field magnet; (2) the armature; (3) the current-collecting device (Fig. 71).

(1) *The Field Magnet,* which generally forms part of the framework of the machine, is usually an electro-

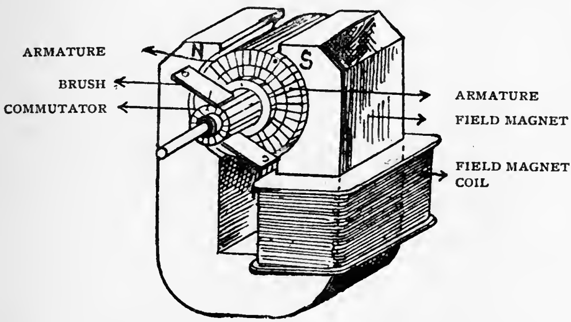


FIG. 71.—Dynamo constructed to generate a Direct Current

magnet, the poles of which have their opposing faces hollowed out to the arc of a circle, in which space the armature revolves. When the field magnet is excited this space will be the seat of a powerful magnetic field. The essential point about the field magnet is that its poles never change; one is always north and the other south.

(2) *The Armature* is the part of the dynamo in which the current is induced by reason of its movement in the magnetic field. In the simple device shown in Fig. 70 it was a single circuit of wire. The armature of a dynamo that generates alternating currents consists of an axle

surrounded by strips of soft iron, upon which are wound several turns of insulated copper wire. The free ends of this wire are connected to the current-collecting device.

The armature of a dynamo that is to generate a current that flows in the same direction and with constant strength (the constant current, or direct current) contains several separate coils.

(3) *The Current-collecting Device.*—If an alternating current is to be collected the device consists of two metal rings mounted concentrically on the axle of the armature. They are insulated from each other and the axle. To one of them is fixed one of the free ends of the wire wound round the armature, to the other ring is fixed the other free end. A carbon "collecting-brush" presses against each ring and leads the current to the main circuit. As the axle of the armature revolves, the rings revolve with it, and the carbon brushes collect the current from the rings. The current collected is an alternating current.

If a constant (direct) current is to be collected the collecting device (called in this case a "commutator") consists of a number of copper bars mounted in the form of a cylinder, and insulated from the shaft and from each other. There are as many bars as there are coils on the armature. The beginning of one coil and the end of the coil just preceding it are joined together, and the two are attached to a commutator bar. Two brushes of copper gauze or carbon press against the revolving cylinder and collect the current (see Fig. 71).

Dynamos and Motors: Motor Transformers.—The dynamo that generates a *direct* current is a reversible machine. That is to say, if another direct current is sent through the armature, the latter will revolve. The dynamo, therefore, now acts as a motor, converting

electrical into mechanical energy. Motors are also constructed so as to work when supplied by an alternating current. Electric motors are used in medicine for several purposes, for working drills and trephines, for applying massage and vibration, etc.

Electric motors are used for another purpose. They can be used to work dynamos constructed to generate a new current of a kind different from that which works the motor. A combination of a motor and dynamo for this purpose is called a "motor transformer." A motor transformer is an exceedingly useful machine and is extensively used now in electro-medical work. It serves the following purposes :—

(1) A constant (direct) current—from the main or from accumulators—can be converted into an alternating (sinusoidal) current.

(2) An alternating current can be converted or transformed into a direct current.

(3) By combining a motor and a dynamo it is possible to convert a direct current at a high voltage into another direct current at lower voltage. By such an arrangement the circuit in which a patient is placed can be kept distinct and separate from the main circuit, so that the risk attending the use of the direct current from the main for medical purposes is avoided.

A motor transformer is constructed on the following plan :—On the lengthened axis of a motor is fixed another independent armature, which revolves between the poles of another field magnet. The armature and the current-collecting device can be arranged so that the new current is either alternating or direct, while the number of turns of wire on the armature will determine the voltage and amperage of the new current.

It is not essential to have an independent field magnet and armature. The other armature may have two separate sets of windings on it, forming a double

armature, and the same magnetic field will serve for this double armature.

Static Transformer.—A motor transformer can be used for the purpose of converting an *alternating* current into another *alternating* current with a different voltage and

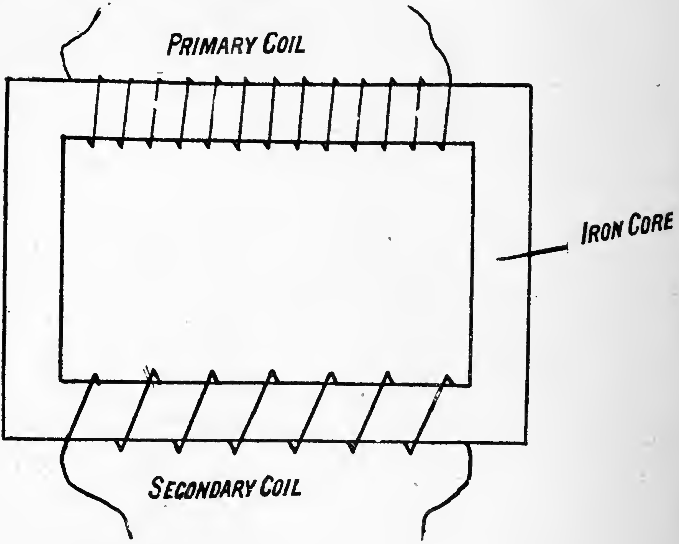


FIG. 72.—Plan of a Static Transformer

amperage, but a much more efficient and less costly apparatus for the purpose is the "static transformer." It is called a *static* transformer because there are no moving parts. It consists of a core of soft wire made in the form of a ring or a square (Fig. 72). A coil of insulated wire is wound around one side. Another independent coil, also of insulated wire, is wound on the opposite side. The alternating current is led through one of these coils. As it alternates backwards and forwards a varying magnetic field is set up in the core ; as a result, new

alternating currents are induced in the other coil. The latter coil is known as the secondary coil, to distinguish it from the other coil, which is known as the primary coil. The voltage and amperage of the current that is induced in this secondary coil depends on the number of turns it contains as compared with the number of the primary. To take an example. Suppose that the primary coil has 100 turns of wire and that the alternating current supplied to it has a pressure of 100 volts, and that we wish to obtain a current to heat a cautery which requires a pressure of, say, 5 volts. The primary has one turn per volt and theoretically the same will be right for the secondary—in this case five turns. It will be found that this will come out about right, and if the wire of the secondary has been chosen sufficiently thick plenty of current will be available for even the largest cautery used in surgery. A transformer regulates itself in a most perfect manner.

As we draw off current from the secondary this relieves the primary of so much of its self-induction, and consequently more current flows in. In a well-designed transformer very nearly the same amount of energy is available from the secondary side as is supplied to the transformer on the primary side. Supposing we have one which is designed to take 10 amperes at 100 volts through the primary. This is equivalent to 1000 watts. According as the secondary is wound we can have from it 200 amperes at 5 volts, 1 ampere at 1000 volts, or 0·1 ampere at 10,000 volts. The alternating current transformer is the most efficient instrument we possess. For those who have an alternating current available, a transformer which will give any voltage desired is a most useful appliance and will well repay any trouble or expense incurred in obtaining it.

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